SCIENCE IN ACTION **THE HUMAN BODY** **PLANET EARTH** **AMAZING ANIMALS**

HOW IT WORKS
BOOK OF
Junior Science

Everything you need to know about science and the world we live in

Over 1,600 fun facts & amazing trivia

Welcome to

HOW IT WORKS BOOK OF Junior Science

We humans have always been fascinated by our world, and over hundreds of thousands of years we've built up a body of knowledge about the things around us, so we know what they are, how they work, how they interact, and what the processes are underlying everything from the patterns birds make when they fly in formation to the forces that hold us all on the ground. This is science, and it is one of the most inspiring and vast voyages that mankind has ever made. This second revised edition of the How It Works Book of Junior Science has been jam-packed full of the most amazing things about our planet, our bodies, the animals we share the world with, and the science supporting it all. It's been written to feed young minds with the incredible stories behind supervolcanoes and moonquakes, magnetism, deep sea creatures and the cells in your body, and to inspire the next generation of scientists to continue exploring, as there is still so much to discover.

Enjoy the book!

HOW IT WORKS BOOK OF Junior Science

Imagine Publishing Ltd
Richmond House
33 Richmond Hill
Bournemouth
Dorset BH2 6EZ
☎ +44 (0) 1202 586200
Website: www.imagine-publishing.co.uk
Twitter: @Books_Imagine
Facebook: www.facebook.com/ImagineBookazines

Publishing Director
Aaron Asadi

Head of Design
Ross Andrews

Production Editor
Alex Hoskins

Senior Art Editor
Greg Whitaker

Design
Perry Wardell-Wicks

Photographer
James Sheppard

Printed by
William Gibbons, 26 Planetary Road, Willenhall, West Midlands, WV13 3XT

Distributed in the UK, Eire & the Rest of the World by
Marketforce, Blue Fin Building, 110 Southwark Street, London, SE1 0SU

Tel 0203 148 3300
www.marketforce.co.uk

Distributed in Australia by:
Network Services (a division of Bauer Media Group), Level 21 Civic Tower, 66-68 Goulburn Street,
Sydney, New South Wales 2000, Australia
Tel +61 2 8667 5288

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How It Works Book of Junior Science Second Revised Edition © 2014 Imagine Publishing Ltd

ISBN 978-1910155424

Part of the
HOW IT WORKS
bookazine series

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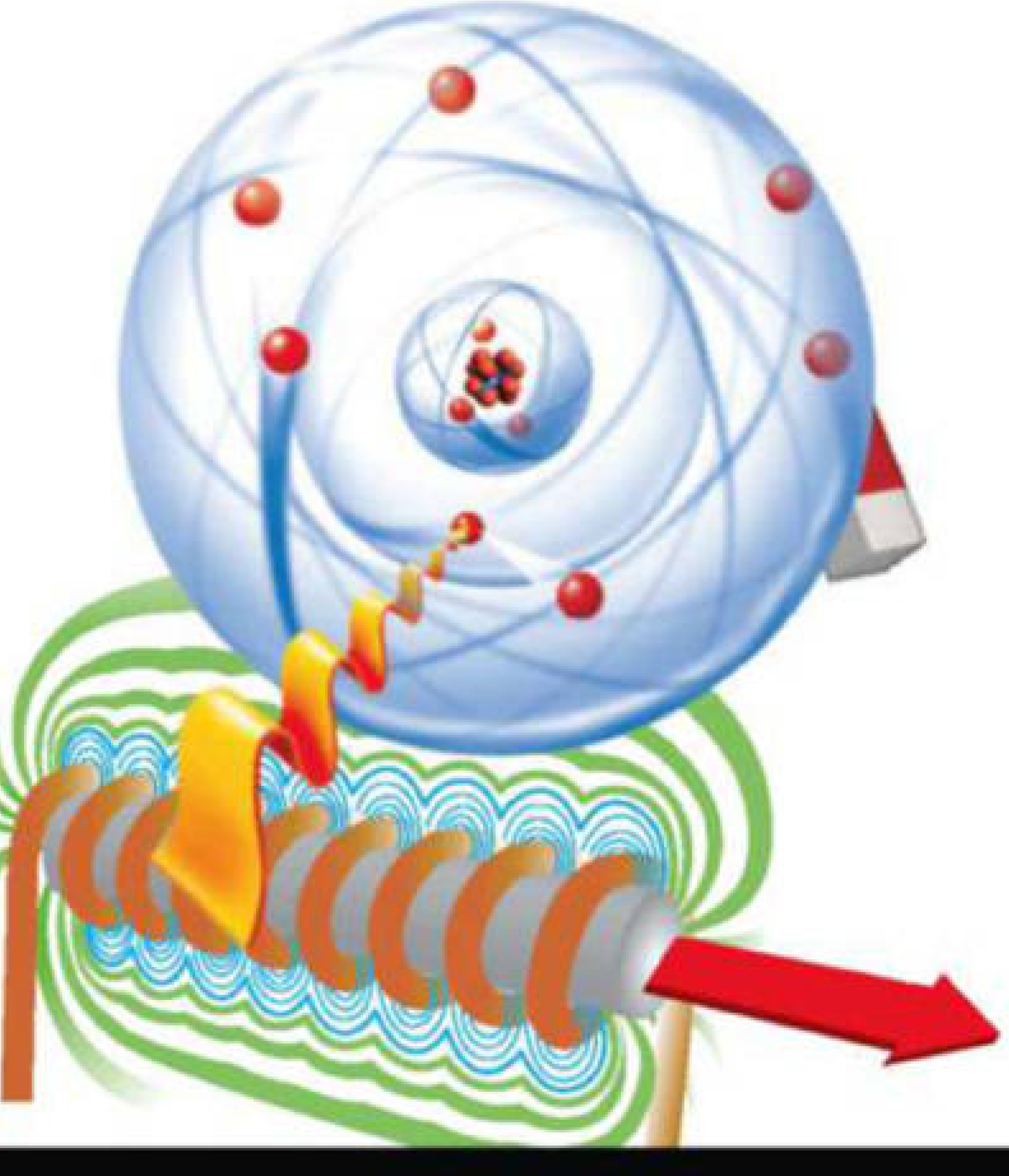
Contents

Science in action

10 Amazing chemistry
16 Atoms
18 Nuclear reactors
20 Building demolition

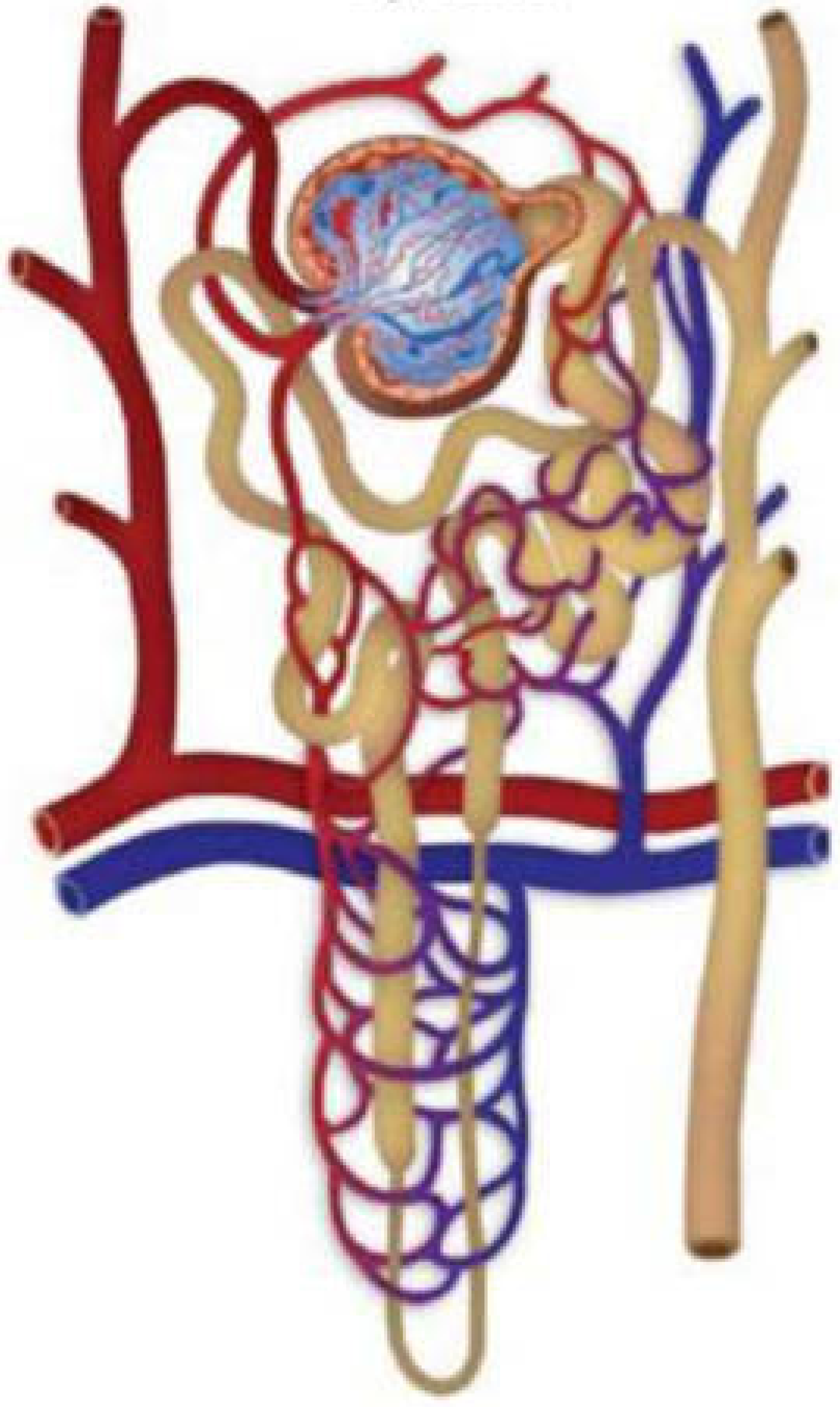
MAGNETISM

22 Explosives
26 The science of fire
30 Noble gases
32 Acids and bases
34 What is condensation?
34 Evaporation and steam
35 States of matter
36 Superconductors
38 Football physics
39 Whirlpools
39 Waterslides
40 Balloon popping
42 How gravity works
46 G-force explained
47 Acceleration
47 The science of skateboarding
48 The power of magnetism



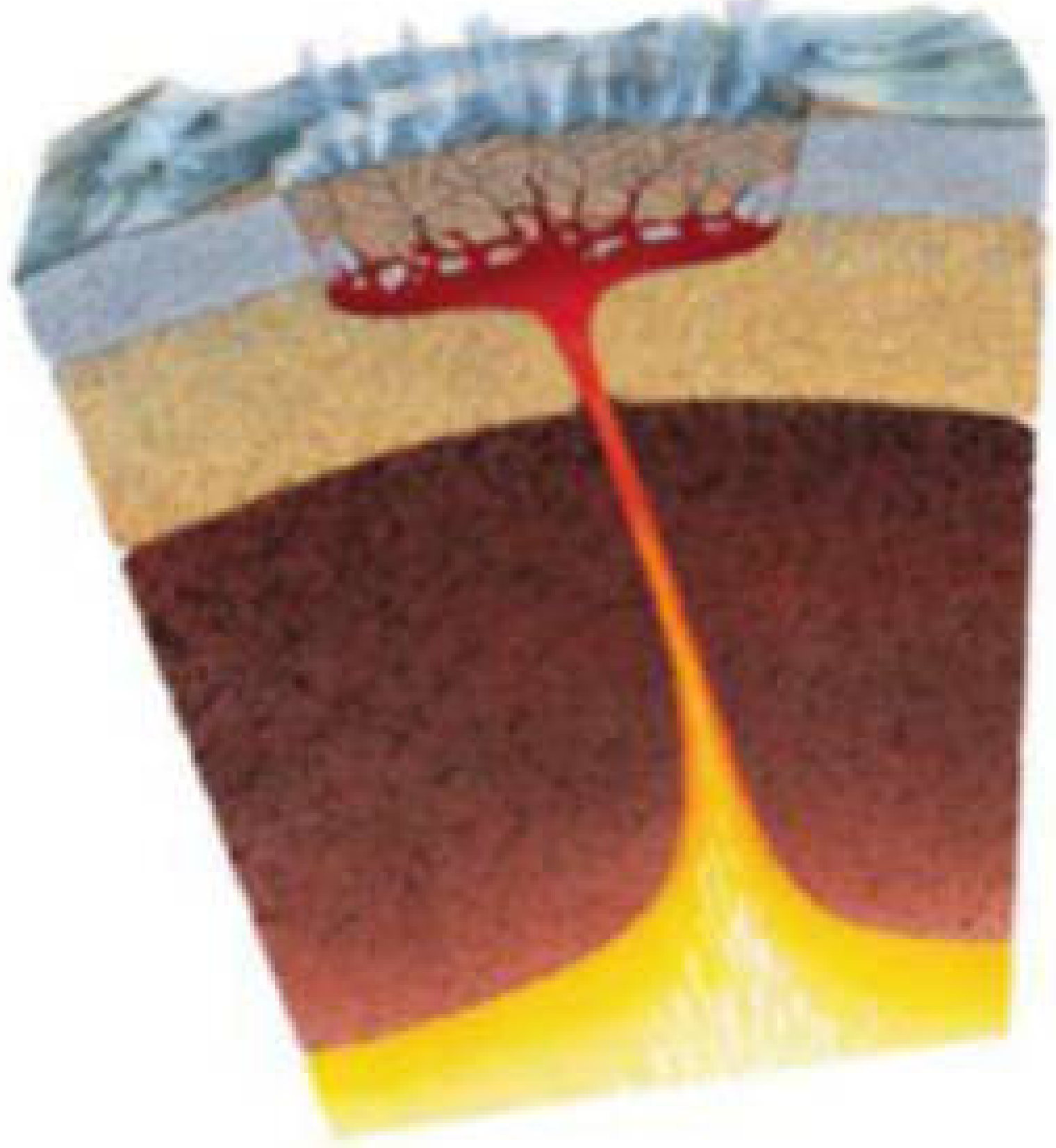
The human body

54 What are you made of?
60 How your blood works
64 Human respiration
66 A look inside your heart
67 How do allergies affect us?
67 Asthma
68 Kidney functions
70 How the liver works
72 The human hand
74 How do your feet work?
76 The human skeleton explained
78 Muscle power
82 What's inside your head?
84 What are moles?
84 Why do we get spots?
85 Tonsils
86 The sensory system



Planet Earth

92 The Earth's structure
94 25 Earthquake facts
98 Whitewater rapids
99 Rogue waves
99 Vegetable sheep
100 Explaining rainforests
104 How plants work
108 How rivers work
110 Avalanche
111 Icebergs explained
111 Hailstones
112 The water cycle
114 The Earth's atmosphere
116 Predicting the weather
118 50 amazing facts about weather
124 The carbon cycle
126 What are fossils?
130 Earth's minerals
132 Super volcanoes



Amazing animals

138 10 Deadliest animals
144 Deadly dinosaurs
148 The life of frogs
150 Frog leaps
151 Super-snappy tongues
152 Amphibian skin
152 Crocodile jaws
153 Death rolls
153 Snakes
154 How whales communicate
154 Venomous fish
155 Dog noses
155 Vampire bat survival
156 Underwater wonders
160 Emperor penguins life cycle
162 Giant Pandas explained
164 A hippo's huge jaws
165 Hibernation explained
165 Ligers and Tigons
166 Flying squirrels
167 Camels
167 Kangaroos
168 How do birds breathe?
168 Earthworms
169 Beaver dams
169 Bats' ultrasonic sonar system
170 Dragonflies
170 Metamorphosis
171 Ladybirds explained
172 Slugs and snails
172 Tardigrades
173 Termite mounds
174 Scorpions

What causes explosions? p22

How do you measure G-force? p46

What are batteries? p21

Science in

10 Amazing chemistry
Earth's most awe-inspiring chemical and physical reactions at an atomic level

16 Atoms
The particles inside all matter, from your fingertips to Halley's comet

18 Nuclear reactors
See the glowing radiation inside the core of a nuclear power plant

20 Building demolition
How are big buildings brought down to the ground?

22 Explosives
The elements of explosions, both man-made and natural

26 The science of fire
Find out what a fire needs to survive, and why fireworks glow different colours

30 How do noble gases work?
What these mostly unreactive gases are used for in our everday lives

32 Acids and bases
How are these two different and what do we use them for?

34 What is condensation?
Discover what happens when your breath condenses up on a window

34 Evaporation and steam
What's the difference between them, and how do they work?

35 States of matter
What are solids, liquids, gases and plasma, and how do they change?

36 Superconductors
The ultimate metal conductors of charge, which work at a frosty -260°C

38 Physics of football
Discover the science behind taking the perfect free kick

39 Water slides
Fun but also fascinating trips down gravity's well

39 Whirlpools
How swirling water can be extremely dangerous

Why are fireworks different colours? p29
MAGNETISM
What makes whirlpools dangerous? p39

action

40 Balloon exploding
What is it about latex that makes a balloon popping sound so loud?

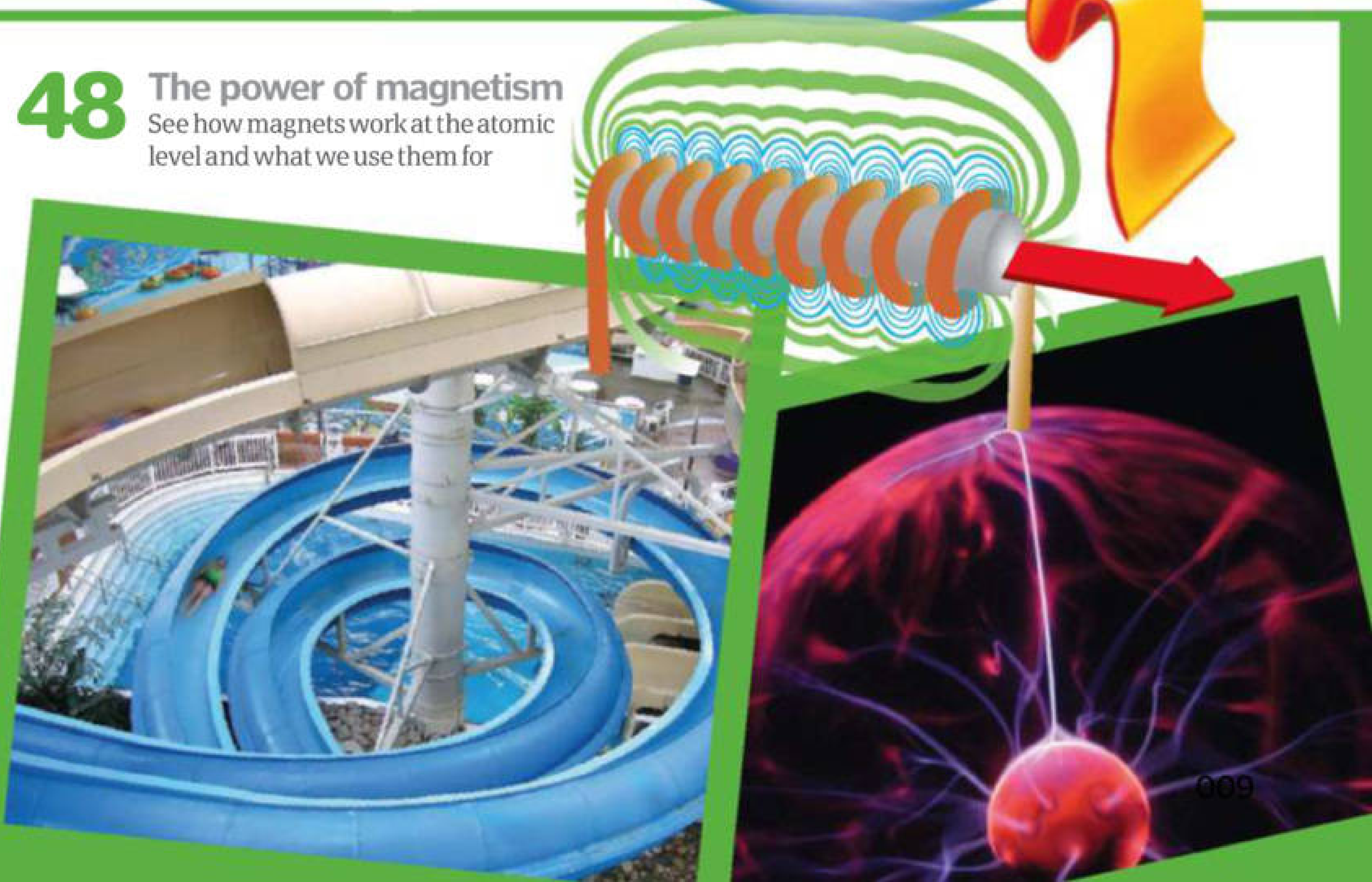
42 How gravity works
You experience it every day, but how does it actually work?

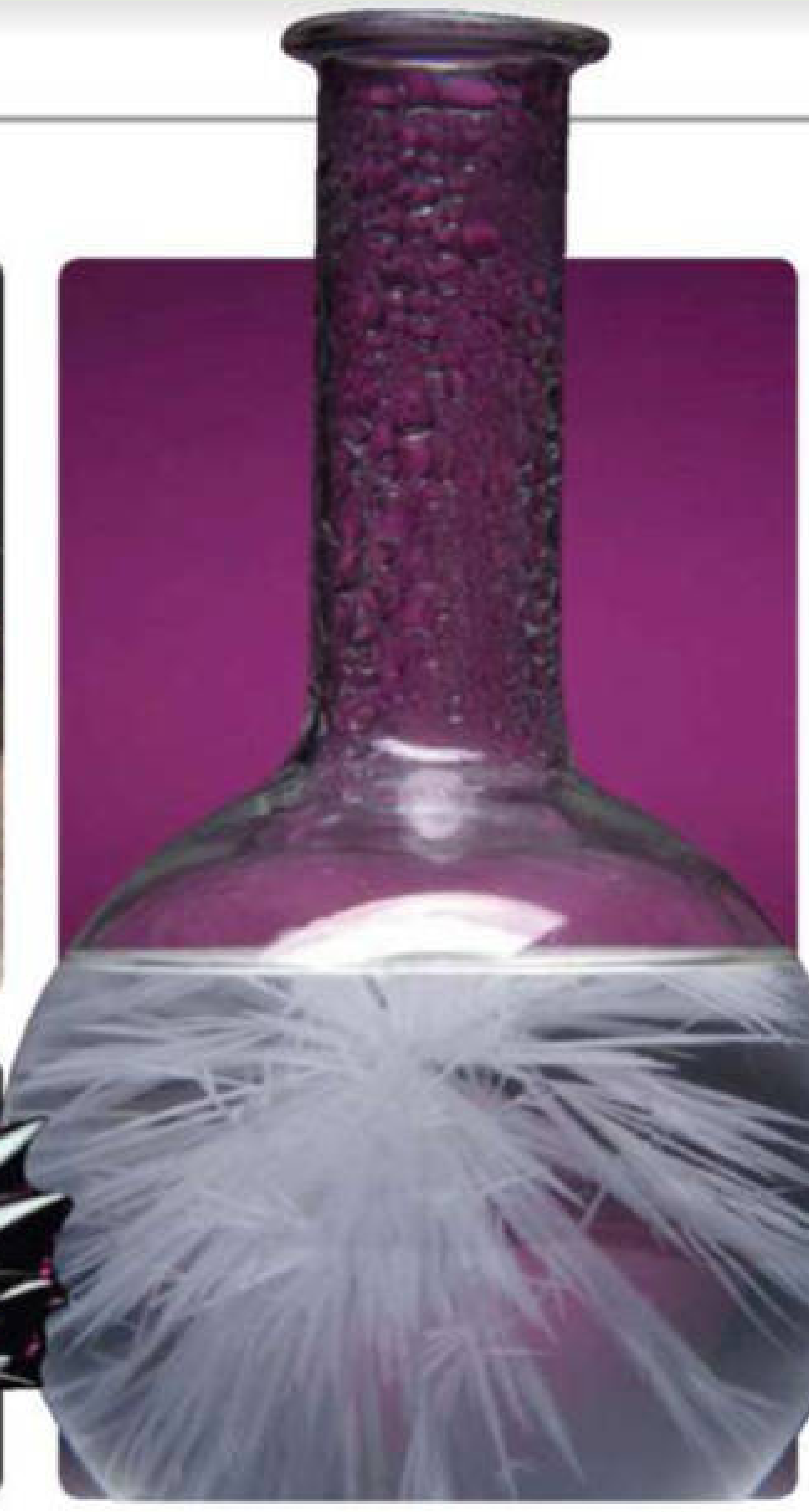
46 G-force explained
The forces that act on us when we quickly accelerate

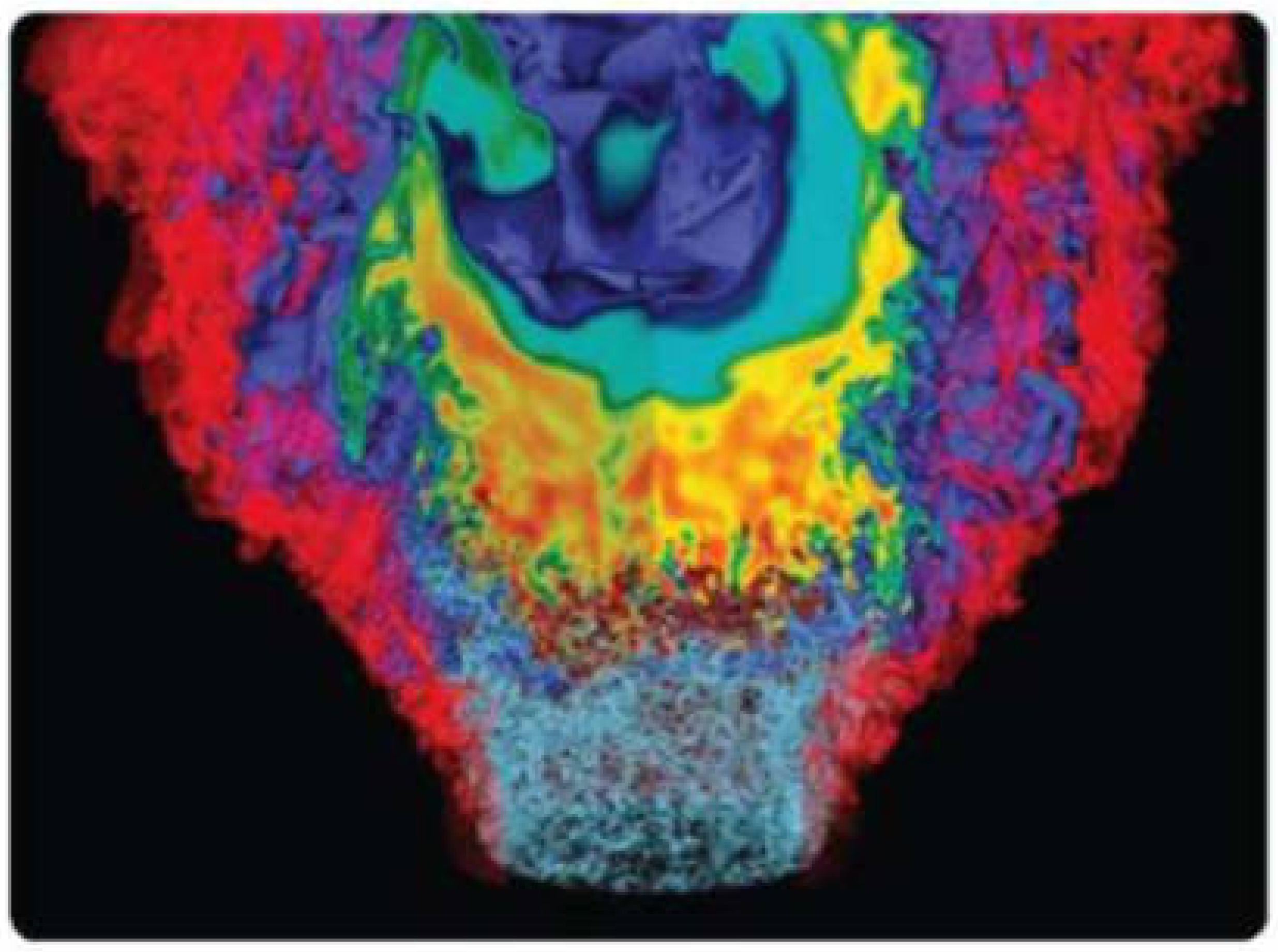
47 Acceleration
What happens when moving things change their speed or direction?

47 The science of skateboards
Discover the physics at work when you drop into a halfpipe

48 The power of magnetism
See how magnets work at the atomic level and what we use them for







Amazing chemistry

Learn about some of Earth's most awe-inspiring chemical and physical reactions at an atomic level

Chemistry is a fascinating subject. The way atoms behave determines everything from the food we eat and the clothes we wear, to our genetic makeup and how we feel. The beautiful simplicity of the periodic table describes just 118 elements that form every known material – 98 if you discount those that can only exist in a laboratory. These elements react in a variety of ways, forming hundreds of millions of compounds – two or more elements bonded together – giving us the diversity of materials that make up our world.

Some reactions are physical, not chemical, and the way to tell is whether or not there has been a change in the chemical formula. Melting ice is a physical change because water is the same substance as ice, just in a different state of matter. Burning coal, on the other hand, is a chemical change, as coal and oxygen combine to make carbon monoxide – a chemically unique material. A chemical reaction drives the change of one substance into another and the reactions are generally identified by colour changes or a release of energy – often in the form of heat, light and sound: the ingredients of an explosion.

It is impossible to cover the astonishing range of chemical reactions that happen in our universe in one article, so we've picked the standout ones which have dramatic results.

Reaction types

Distinguishing between physical and chemical reactions is one thing, yet chemists have identified five common ways that chemical changes can be broken down further. These are: synthesis, decomposition, single replacement, double replacement and oxidation/reduction (redox).

Some reactions can exhibit characteristics of more than one of these labels and don't fit neatly into a category, as all chemical reactions are caused by the sharing, gaining or losing of electrons. However it's helpful to categorise reactions by the distinct ways in which they behave.

Synthesis

A synthesis reaction occurs when two or more chemical elements or compounds react together to make a more complicated compound. For example – burning hydrogen (H2) and oxygen (O2) gas forms the more complex water molecule (H2O).

Ⓐ+Ⓑ → Ⓐ Ⓑ

Decomposition

Decomposition is the breaking down of two or more complex molecules into simpler ones. Passing an electric current through water (H2O), results in the 'decomposition' of the water molecule into its basic elements: hydrogen (H_2) gas and oxygen (O_2) gas.

Ⓐ-Ⓑ → Ⓐ+Ⓑ

Single replacement

When one element is bumped by another in a compound, it's a single replacement reaction. Reactions with metals and acids often fall into this group. Magnesium (Mg) and hydrochloric acid (HCl) react to form magnesium chloride (MgCl2) and hydrogen (H2), where Mg replaces H2.

Ⓐ-Ⓑ+Ⓒ → Ⓐ Ⓒ+Ⓑ

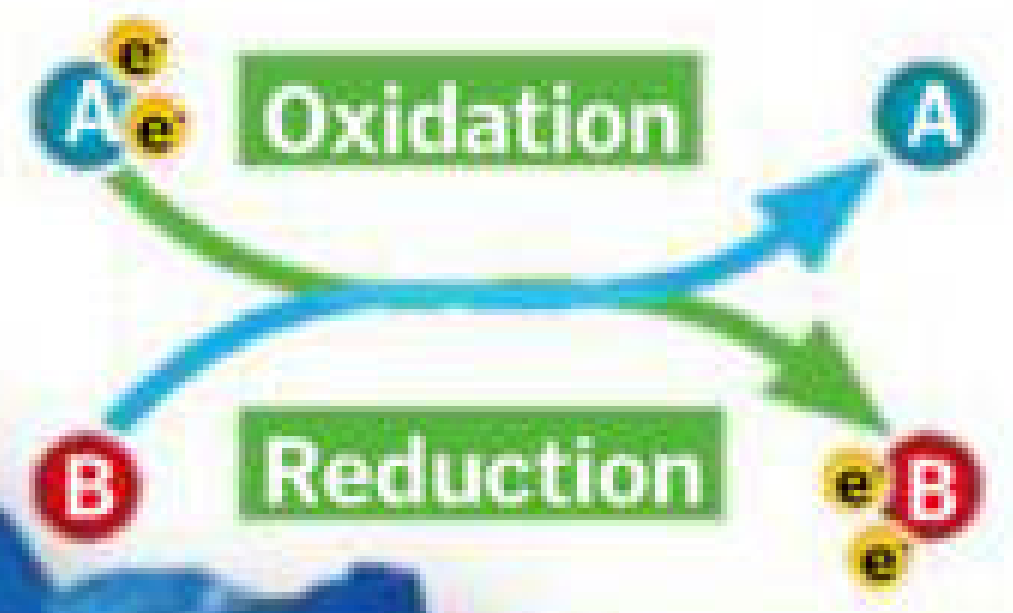
Double replacement

In some cases, compounds 'swap' their components – this is called a double replacement reaction. For example, hydrochloric acid (HCl) and sodium hydroxide (NaOH) react together, producing sodium chloride (NaCl) and water (H2O). In this reaction, the hydrogen and sodium atoms have switched places.

Ⓐ-Ⓑ+Ⓒ-Ⓓ → Ⓐ-Ⓒ+Ⓑ-Ⓓ

Redox

Oxidation and reduction (ie redox reactions) describe a chemical change where electrons are transferred. You can't have oxidation (loss of electrons) without reduction (gain of electrons). When H2 burns with O2, the H2 becomes oxidised and the O2 is reduced.



Thermite reaction

☠☠☠☠

☒ In nature ☑ In lab ☒ At home ☒ Toxic

Thermite is a very cool – well, hot – reaction that consists of metal powder and a metal oxide (most often aluminium and iron oxide); the latter more commonly known as rust. The characteristics of thermite reactions are not so much explosive; rather it's their ability to heat very small areas to incredibly high temperatures where they excel. You may not think of metals as burning very easily, but in the right conditions – and very high ignition temperatures – they can.

Thermite reactions are used for welding train tracks together and temperatures as high as 2,500 degrees Celsius (4,532 degrees Fahrenheit) can be reached. Due to the blazing heat, products of thermite reactions are liquid, making them perfect for welding. As thermite reactions have their own supply of oxygen from the metal oxide they can work even in the absence of air, such as underwater and in space. Aluminium and iron oxide are heated, often with magnesium ribbon as a fuse, and oxygen from the iron oxide breaks its bond to combine with the aluminium to form aluminium oxide and iron. Special face masks with UV protection must be worn for safety when welding due to the intense radiation.

Copper sulphate crystals

Deadliness: ☠

Ingredients: Copper sulphate pentahydrate (CuSO4*5H2O); water (H2O) Core process: Crystallisation

☑ In nature ☑ In lab ☑ At home* ☑ Toxic

*(But take care as copper sulphate can be a mild irritant)

What it lacks in explosive power, copper sulphate more than makes up for in its looks, creating brilliant blue crystals when its hydrated form is dissolved in hot water. Copper sulphate is a type of salt, and is most commonly encountered as a powder – copper sulphate pentahydrate (CuSO4*5H2O). This is a way of expressing five water molecules are attached to the copper sulphate molecule; it is hydrated. For crystals to form, copper sulphate pentahydrate is added to hot water to the point where no more can dissolve. This is called a saturated solution, and a hotter solution can dissolve more copper sulphate than a colder one. When the solution starts to cool, not all of the copper sulphate can exist in a dissolved state, so molecules gather in a repeating pattern, forming crystals. This is a physical change as the material is altering its structure rather than its makeup. Suspending a nylon wire in the solution gives a surface for the crystals to latch on to and grow. Eventually the water evaporates, but copper sulphate can't, so continues crystallising until no water is left.

Top five deadliest reactions

1 Hydrochloric acid and most things…
Hydrochloric acid (HCl) is an extremely strong acid. HCl reacts with most things – especially bases – and can corrode metal, cause chemical burns and even release flammable hydrogen.

2 Acid rain
When sulphur dioxide is released into the air, it rises up and reacts with hydrogen peroxide which is found in some clouds. Sulphuric acid – a product of the reaction – falls back down to Earth and can have devastating effects on flora, fauna and buildings/statues, etc.

3 Nitroglycerine and heat
Nitroglycerin is one of the most explosive substances there is. The oily liquid is so sensitive that the slightest jolt or increase in heat can trigger a massive explosion.

4 Bleach and ammonia
When ammonia and bleach are mixed, the bleach decomposes to form hydrochloric acid. Ammonia and chlorine gas react to form a deadly vapour: chloramine.

5 Mustard gas
The volatile combination of sulphur dichloride and ethylene reacts to form a cyclic sulphonium ion. This reacts adversely with parts of the DNA preventing cells from replicating, leading to tissue necrosis.

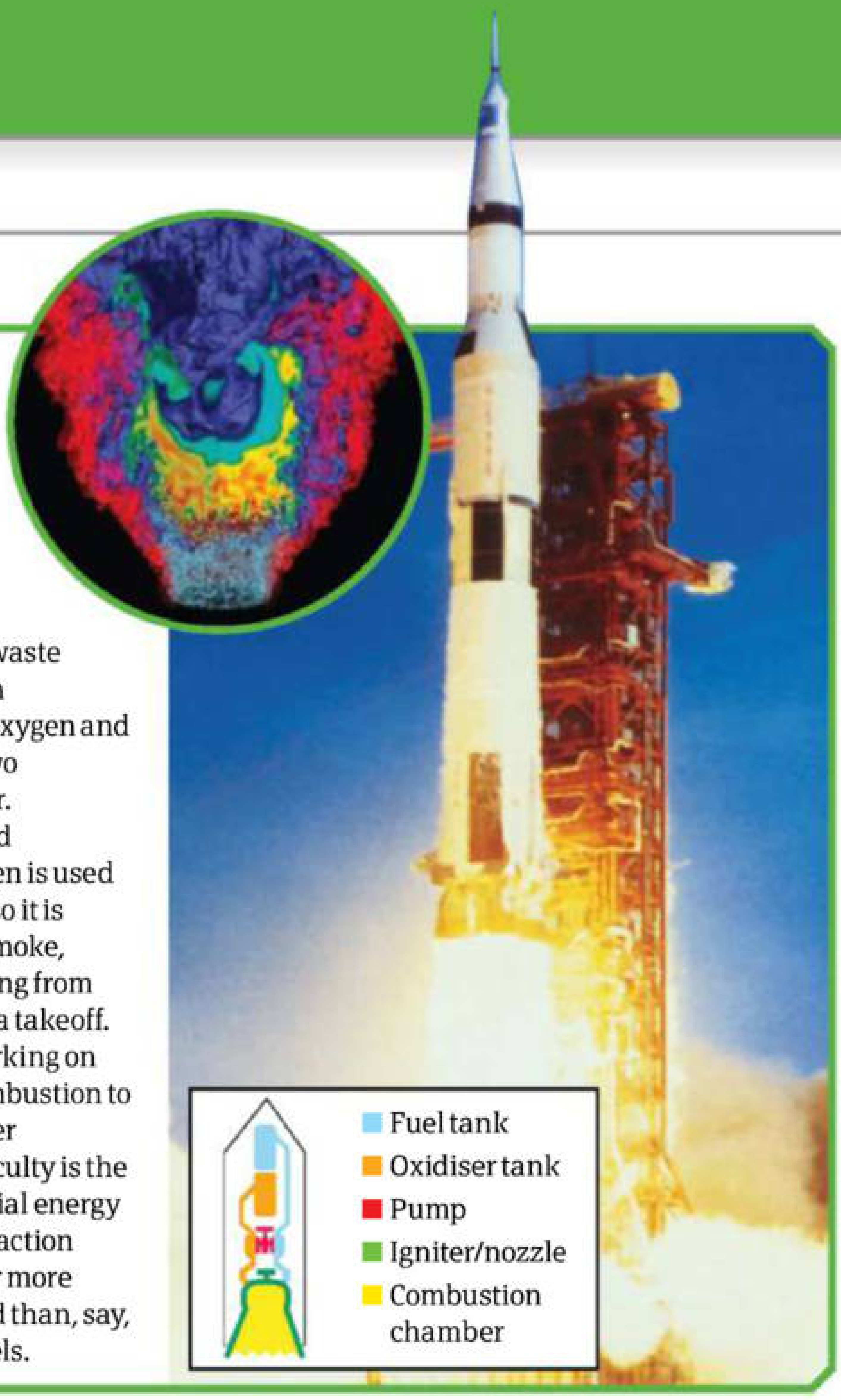
Burning hydrogen

Deadliness: ☠☠☠
Ingredients: Hydrogen (H_2); oxygen (O_2)
Core process: Redox

☒ In nature ☑ In lab ☒ At home ☒ Toxic

Hydrogen (H_2) is the lightest, most abundant element in the universe, yet it's also one of the most flammable. Hydrogen is quick to burn in the presence of oxygen (O_2) and can be very explosive. This powerful stuff is even used as the primary fuel for combustion when launching space shuttles. When hydrogen burns, large quantities of heat and light are given off. The light emitted when pure hydrogen and oxygen react is mainly ultraviolet, making the flame almost invisible – however, there are often other materials present, creating a visible flame. Water is the waste product of hydrogen combustion, since oxygen and hydrogen are the two ingredients in water. Combustion of liquid hydrogen and oxygen is used to launch rockets – so it is water vapour, not smoke, which you see coming from the exhaust during a takeoff.

Scientists are working on using hydrogen combustion to power cars and other machines. The difficulty is the large amount of initial energy needed to get the reaction going. It requires far more energy to get started than, say, traditional fossil fuels.



Magnesium and Teflon

Deadliness: ☠☠☠
Ingredients: Magnesium (Mg); Teflon ($[C_2F_4]_n$)
Core process: Redox

☒ In nature ☑ In lab ☒ At home ☒ Toxic

Magnesium (Mg) is a highly reactive element which burns at a staggering 3,100 degrees Celsius (5,612 degrees Fahrenheit), giving off an intense white light. In addition to visible light, magnesium emits infrared (IR) when burned, making it perfect for use in military countermeasures such as decoy flares. Like all things, magnesium needs to be in the presence of an oxidiser when it burns – a material which takes electrons from the fuel allowing the reaction to occur. Flares are made of Teflon ($[C_2F_4]_n$) and magnesium, and it's the fluorine in Teflon that oxidises magnesium. Fluorine is a stronger oxidiser than oxygen, as it wants to accept electrons more than oxygen, allowing for a higher temperature of combustion. Heat-seeking missiles lock on to infrared light given off by engines in aircraft, but magnesium decoy flares throw out far more IR light than aeroplane engines, effectively confusing the missiles' heat-seeking guidance systems and hopefully deterring the weapon from its target.

A magnesium fire cannot be extinguished with water, since the magnesium reacts with water to produce hydrogen gas – which if anything will only intensify the fire. Instead, dry sand is generally used to stop the reaction. Other uses of magnesium have been as an illumination source in flash photography and in fireworks.

Sodium acetate supersaturation

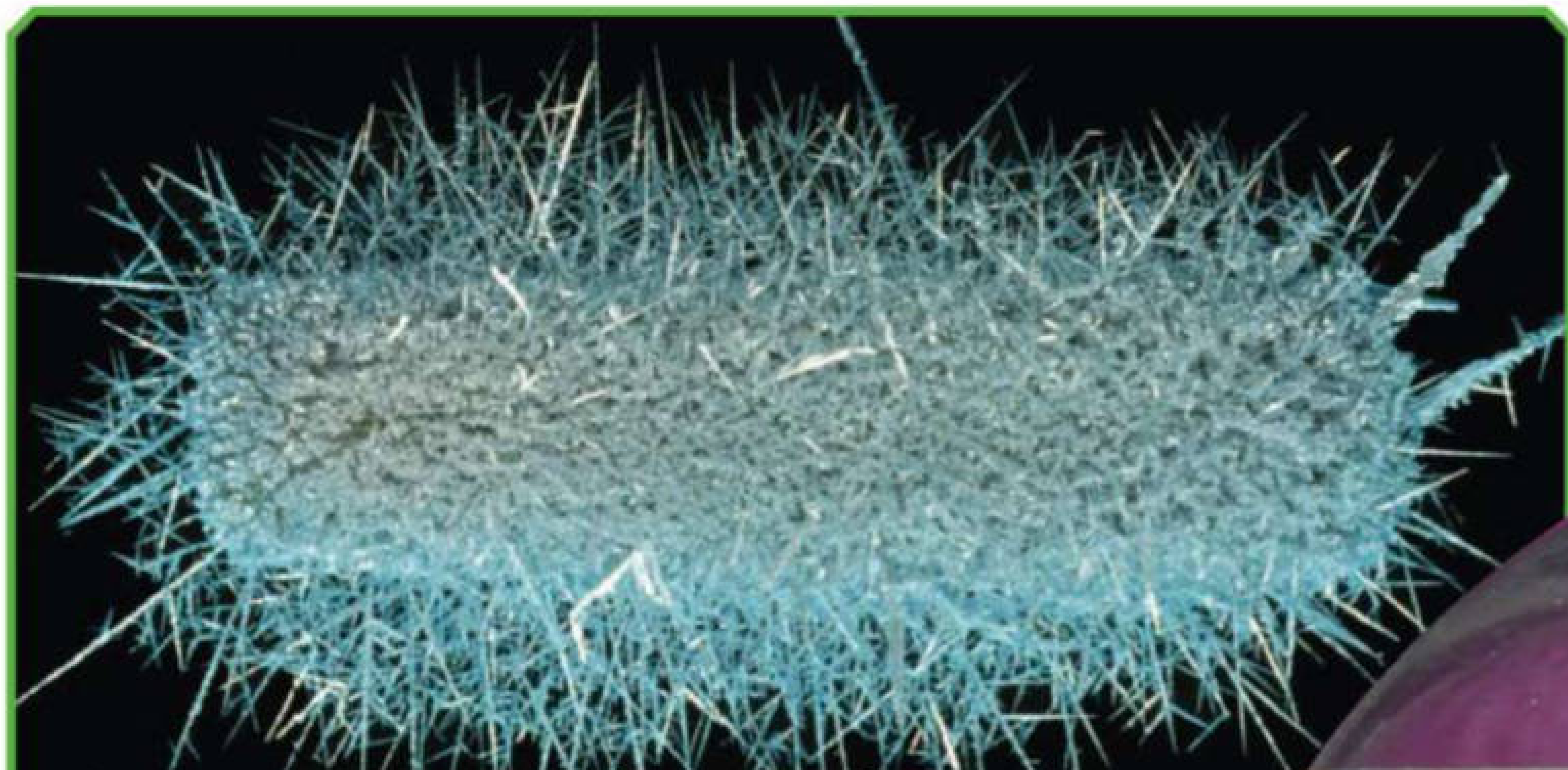
Deadliness: ☠

Ingredients: Sodium acetate ($NaC_2H_3O_2$); water (H_2O) Core process: Crystallisation

☒ In nature ☒ In lab ☑ At home* ☒ Toxic

*(But take care as sodium acetate can be a mild irritant)

Sodium acetate ($NaC_2H_3O_2$) heated in water then cooled has the unusual property of crystallising into a solid when it is disturbed. It can be poured out of a beaker as a liquid and, upon hitting a surface, becomes a solid that is hot to touch – hence its other name, hot ice. Sodium acetate is a salt which dissolves in water. Heating – to around 100 degrees Celsius (212 degrees Fahrenheit) – then cooling a mixture of the two allows more sodium acetate to dissolve forming a supersaturated solution. The solution exists in a metastable state, like a ball perched at the top of a hill, where it will roll down with the slightest nudge. The nudge can be pouring the solution, or adding a seed crystal, causing the dissolved sodium acetate to leave the solution and return to a solid. In our analogy this is like the ball rolling down the hill until it reaches flat ground. On its way, the solid sodium acetate absorbs three molecules of water, becoming sodium acetate trihydrate ($NaC_2H_3O_2*3H_2O$). These water molecules aren't chemically bonded to the sodium acetate, representing a physical change. The process is exothermic (ie it releases heat) and is used in hand warmers.



Copper and silver nitrate

Deadliness: ☠

Ingredients: Silver nitrate ($AgNO_3$); copper (Cu); water (H_2O)

Core process: Single replacement

☒ In nature ☑ In lab ☒ At home ☑ Toxic

Mixing silver nitrate and copper is one of the most famous chemistry experiments, with it starring in many a school science lesson around the globe. The experiment involves introducing copper – typically a copper wire – to a silver nitrate/water solution and suspending it there for a couple of hours.

The combining of both triggers a single replacement reaction, where copper is changed from its elemental form (Cu) to its blue aqueous ion form (Cu^{2+} [aq]), while the silver ions (Ag^+ [aq]) in the silver nitrate solution will be changed into their elemental metallic form (Ag) and deposited onto the wire. These silver deposits continue to grow off the copper in a series of fractal-like crystals until all reactable copper in the solution is exhausted, leaving the end products of silver and copper nitrate.

The reason this replacement reaction occurs is that the atoms in the copper are oxidised when introduced to the silver nitrate solution, losing electrons and forming copper ions, while the silver ions in the nitrate solution are reduced (ie they gain electrons) into elemental silver.

Once the silver crystals have grown they can be removed from the copper, dried off and then displayed as funky pieces of fractal art.

Potassium and water

Deadliness: ☠☠☠

Ingredients: Potassium (K); water (H_2O) Core process: Redox

☒ In nature ☑ In lab ☒ At home ☒ Toxic

Put a lump of potassium in a dish of water and it will give off a pinkish light, get very hot and skim across the surface at speed. A favourite experiment of many science classrooms, potassium is a metal that reacts violently in the presence of oxygen and water. It forms potassium hydroxide (KOH) and hydrogen gas (H_2). Potassium atoms have 19 electrons – one of which is alone in an outer shell. This makes potassium keen to lose an electron to form a complete outer shell and become more stable. When the reaction begins, the heat given off ignites the hydrogen gas, which reacts with oxygen to produce water. Potassium is so reactive that it must be stored in kerosene, to avoid contact with water vapour in the air. Even oxygen in the air is enough to make potassium spontaneously combust! Because potassium is so reactive, it's not found in its elemental form, but its compound is common.

Potassium chlorate and most things (in this case Jelly Babies)

Deadliness: ☠☠☠

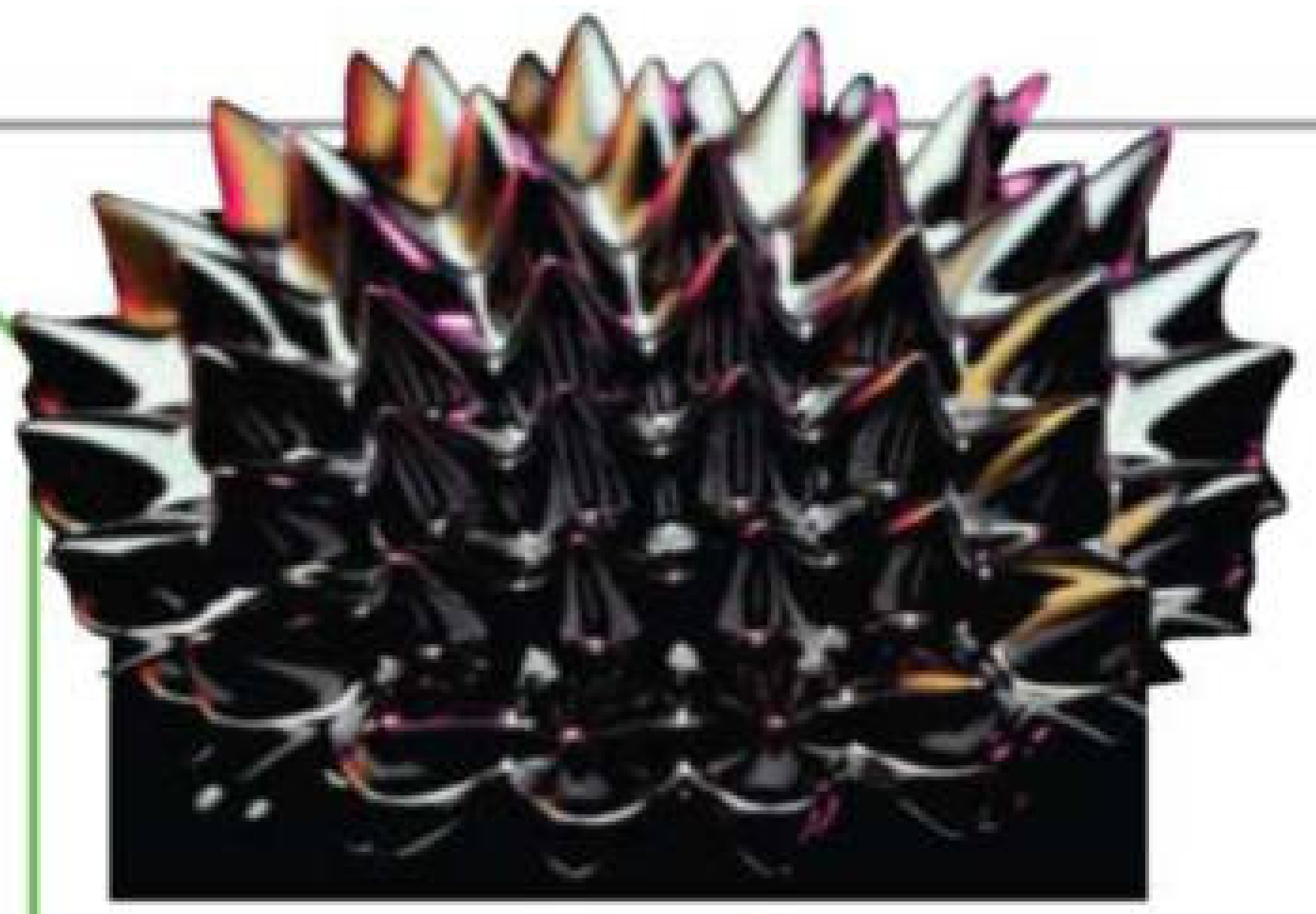
Ingredients: Potassium chlorate ($KClO_3$); Jelly Babies (glucose syrup, sugar, water, gelatine and flavourings) Core process: Redox

✖ In nature ✓ In lab ✖ At home ✓ Toxic

Watching a Jelly Baby meet its demise at the hands of potassium chlorate is spectacular. There's an abundance of energy inside Jelly Babies stored as sugar, released in intense flames and a piercing scream when potassium chlorate is added to the mix.

Potassium chlorate is a powerful oxidiser, taking its form as a white powder and often used in fireworks and explosives. The 'ate' part of chlorate describes the oxygen atoms attached to the chlorine atom, and the chemical formula is $KClO_3$. Chlorate-based oxides are more efficient oxidisers than those in gunpowder and potassium chlorate needs to be handled carefully due to its highly unpredictable tendency to spontaneously ignite.

The reaction happens when a small amount of potassium chlorate is added to a test tube and heated until it becomes a clear liquid. Safety screens and goggles are a must. The Jelly Baby is placed with tongs into the tube and instantly produces lively flames, intense screaming and smoke. The reaction gives off noxious fumes so ventilation is also needed.



Ferrofluid

This experiment combines physics and chemistry to produce an awesome effect. Ferromagnetic fluid is a liquid that undergoes a radical change when introduced to a magnetic field, turning from a puddle into a spiked dome. The fluid does this due to its composition, which is a mix of nanoscale ferromagnetic particles (like iron) and a carrier fluid. The particles are coated with a surfactant – a compound that lowers a liquid's surface tension – ensuring an even distribution of particles. When a magnetic field is introduced – usually a strong magnet positioned beneath it – the particles realign to the magnetic field lines. Contained as they are, the particles cause the liquid to act like a solid.

Flame test

The flame test is one of the simplest yet coolest experiments in the lab. By introducing certain elements – generally metals – to a Bunsen burner, you can determine their composition by analysing the emission spectrum. This works as the heat excites the material's ions, so they emit visible light. For example, if you have a chunk of unknown metal, by introducing it to a calibrated burner (one that is not contaminated) and evaluating the colour(s) of the flame, you can determine what the substance is made of. Copper (Cu) emits a blue-green flame, lithium (Li) a bright red one, while the image above shows the orange/crimson flame generated by strontium (Sr).

Carbon disulphide and nitrous oxide

Deadliness: ☠☠☠

Ingredients: Carbon disulphide (CS_2); nitrous oxide (N_2O)

Core processes: Decomposition; redox

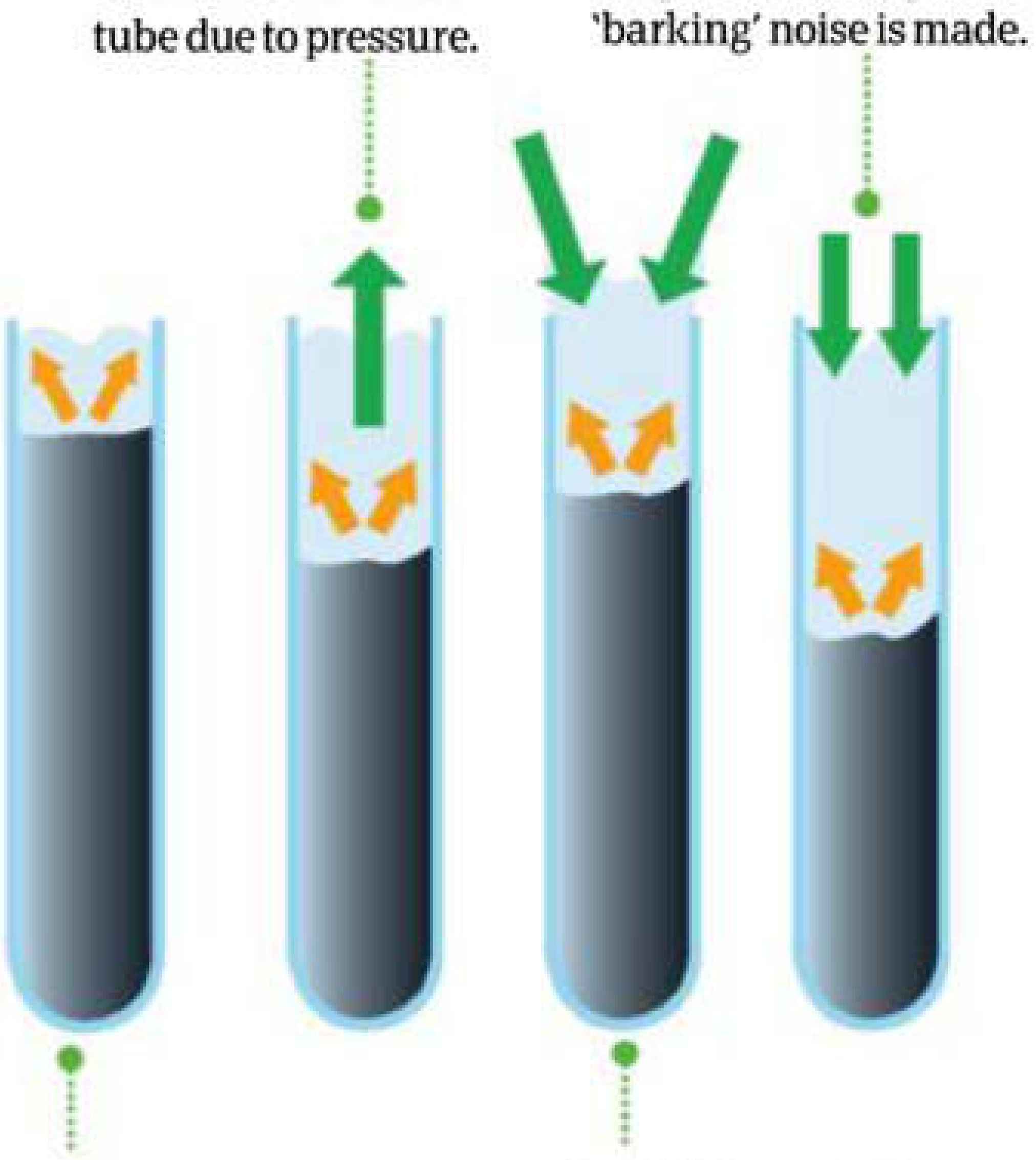
☑ In nature (the reactants) ☑ In lab ☒ At home ☑ Toxic

The barking dog reaction is a consequence of igniting carbon disulphide (CS_2) mixed with nitrous oxide (N_2O), better known as laughing gas. The reaction creates a bright flash of blueish-purple light and heat, and, more bizarrely, a sound like a dog barking.

Nitrous oxide gas is the source of oxygen – ie the oxidiser – needed to burn the colourless liquid fuel, carbon disulphide. When the reaction takes place in a confined space – such as a long tube – some energy is converted to form the loud barking noise, due to a fluctuation of pressure. This is an example of a reaction which makes elements from compounds: in this case a yellow coating of sulphur and nitrogen gas are the elements left behind.

Carbon disulphide is found in nature as a product of metabolic processes in plants and volcanic eruptions. Nitrous oxide also forms naturally from some species of bacteria, plus through industry and agriculture, and depletes ozone in the stratosphere.

Used in the past in flash photography, the flash it gives off is so bright that many people in the photographs would look startled. The pervasive smell probably didn't make it popular either.



1. Energy release
Nitrous oxide reacts with the carbon disulphide releasing energy as heat, expanding the gases.

2. Expansion
As the gases expand, those near the top are forced out of the test tube due to pressure.

3. Differential
The expelled gases lead to a pressure drop within the tube, creating a vacuum-like effect.

4. Bark
As the gases rush back into the tube to balance the pressure, a repeated 'barking' noise is made.

Potassium nitrate and sugar

Deadliness: ☠☠

Ingredients: Potassium nitrate (KNO_3); sucrose ($C_{12}H_{22}O_{11}$)

Core process: Redox

☒ In nature ☑ In lab ☒ At home ☑ Toxic

There's something strangely satisfying about witnessing the volatile display of smoke, colour and fire given off by the mixture of potassium nitrate, sugar and heat. The amount of fire varies, but there is always an abundance of smoke. You have most likely seen this reaction at a firework display, or from the smoke stunt planes deploy where coloured dyes are often added for effect.

Potassium nitrate (KNO_3) – aka saltpetre – is an essential in any pyrotechnics cookbook; it's one of the main ingredients in gunpowder, for example. Potassium nitrate works as an oxidiser, giving off oxygen and promoting the burning of fuel.

As seen in the 'Screaming Jelly Baby', sugar is an extremely effective fuel; it contains energy that 'burns' in our bodies and converts to useful energy we use to perform any physical activity. When heat is applied to saltpetre and sugar, the saltpetre loses an oxygen atom – transitioning from KNO_3 to KNO_2 and oxidising the sugar. The sugar burns, releasing smoke which rapidly expands and can generate enough thrust to lift a small rocket.

Interestingly there's a programme called Sugar Shot to Space that aims – as you would probably be able to guess – to launch a rocket powered by sugar propellant alone beyond Earth's atmosphere.

Useful reactions

1 Photosynthesis
The chemical process of turning sunlight into energy is vital to life, allowing plants to grow and release their waste product: oxygen. As well as regulating the levels of oxygen in the atmosphere, photosynthesis is the main source of energy for most organisms.

2 Baking bread
In times when other food sources were scarce, the discovery of heating flour mixed with water combined with yeast fermentation was a breakthrough. Yeast ferments sugars and carbohydrates giving off CO_2.

3 Extraction of metals
One of the world's largest industries, extracting metals from their ores using chemical reactions is hugely important, as most metals are mixed with impurities in their natural state.

4 Galvanising steel
From lampposts to buildings steel is everywhere around us and protecting these things from rust is vital. Dipping steel in a bath of zinc causes a chemical reaction which adheres a coating of zinc to the steel to protect it from water vapour.

5 DNA production
The essential 'code' for all known life, DNA is a molecule with our genetic instructions in the form of nucleotides – a set of long polymers made of sugars and phosphates. Chemical reactions allow the DNA to form, replicate and interact with proteins to make us who we are.

Atoms

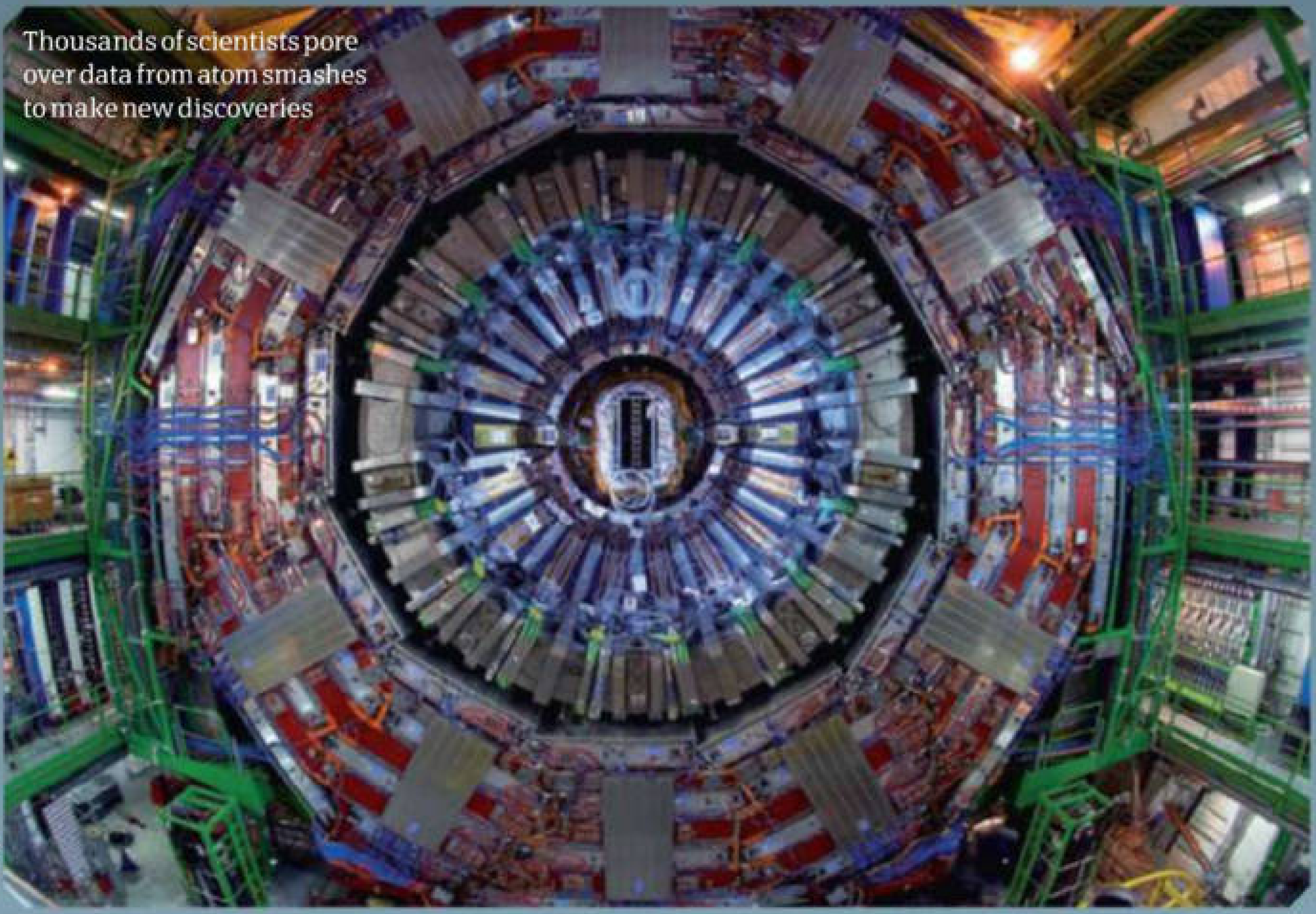
Up and atom with our look at these particles inside all matter in the universe

At the centre of every atom is a nucleus containing protons and neutrons. Together, protons and neutrons are known as nucleons. Around this core of the atom, a certain number of electrons orbit in shells. The nucleus and electrons are referred to as subatomic particles. The electrons orbit around the centre of the atom, which is due to the charges present; protons have a positive charge, neutrons are neutral and electrons have a negative charge. It is the electromagnetic force that keeps the electrons in orbit due to these charges, one of the four fundamental forces of nature. It acts between charged objects – such as inside a battery – by the interaction of photons, which are the basic units of light.

An atom is about a tenth of a nanometre in diameter. 43 million iron atoms lined up side by side would produce a line only one millimetre in length. However, most of an atom is empty space. The nucleus of the atom accounts for only a 10,000th of the overall size of the atom, despite containing almost all of the atom's mass. Protons and neutrons have about 2,000 times more mass than an electron, making the electrons orbit the nucleus at a large distance.

An atom represents the smallest part of an element that can exist by itself. Each element's atoms have a different structure. The number of protons inside a specific element is unique. For example, carbon has six protons whereas gold has 79. However, some elements have more than one form. The other forms – known as isotopes – of an atom will have the same number of protons but a totally different number of neutrons. For example, hydrogen has three forms which all have one proton; tritium has two neutrons, deuterium has one neutron and hydrogen itself has none.

Since different atoms have different numbers of protons and neutrons, they also have different masses, which determine the properties of an element. The larger the mass of an atom the smaller its size, as the electrons orbit more closely to the nucleus due to a stronger electromagnetic force. For example an atom of sulphur, which has 16 protons and 16 neutrons, has the same mass as 32 hydrogen atoms, which each have one proton and no neutrons.

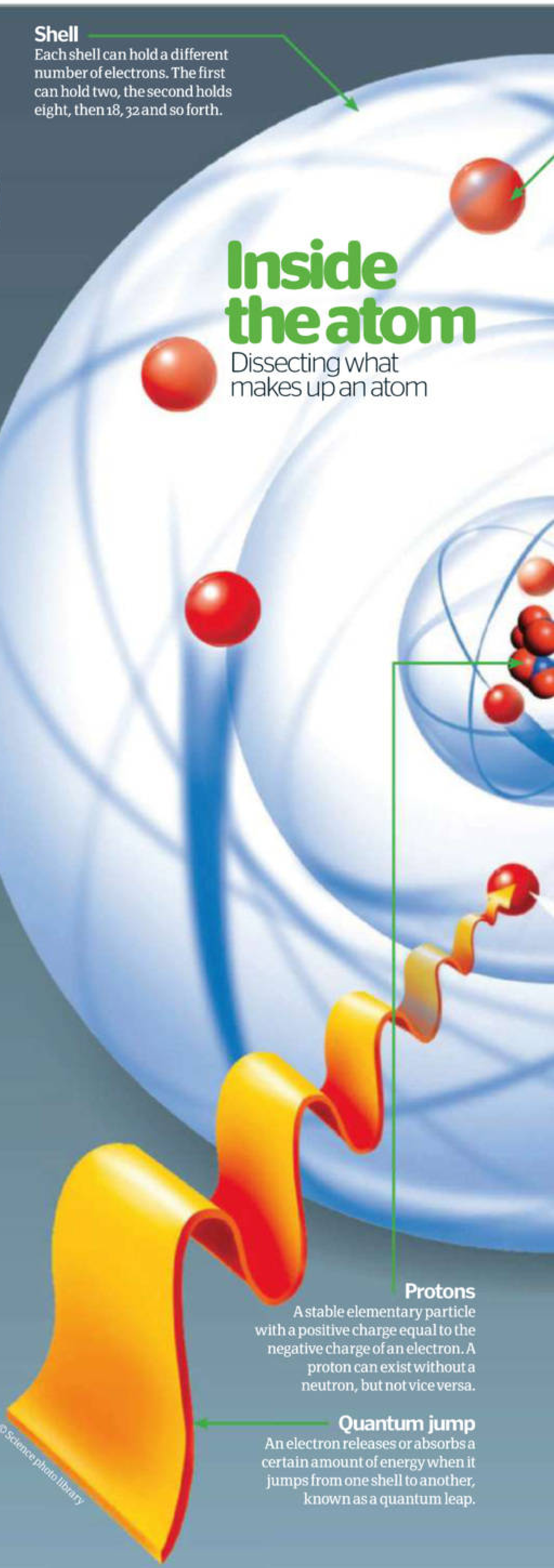


Thousands of scientists pore over data from atom smashes to make new discoveries

© CERN

Inside the atom

Dissecting what makes up an atom

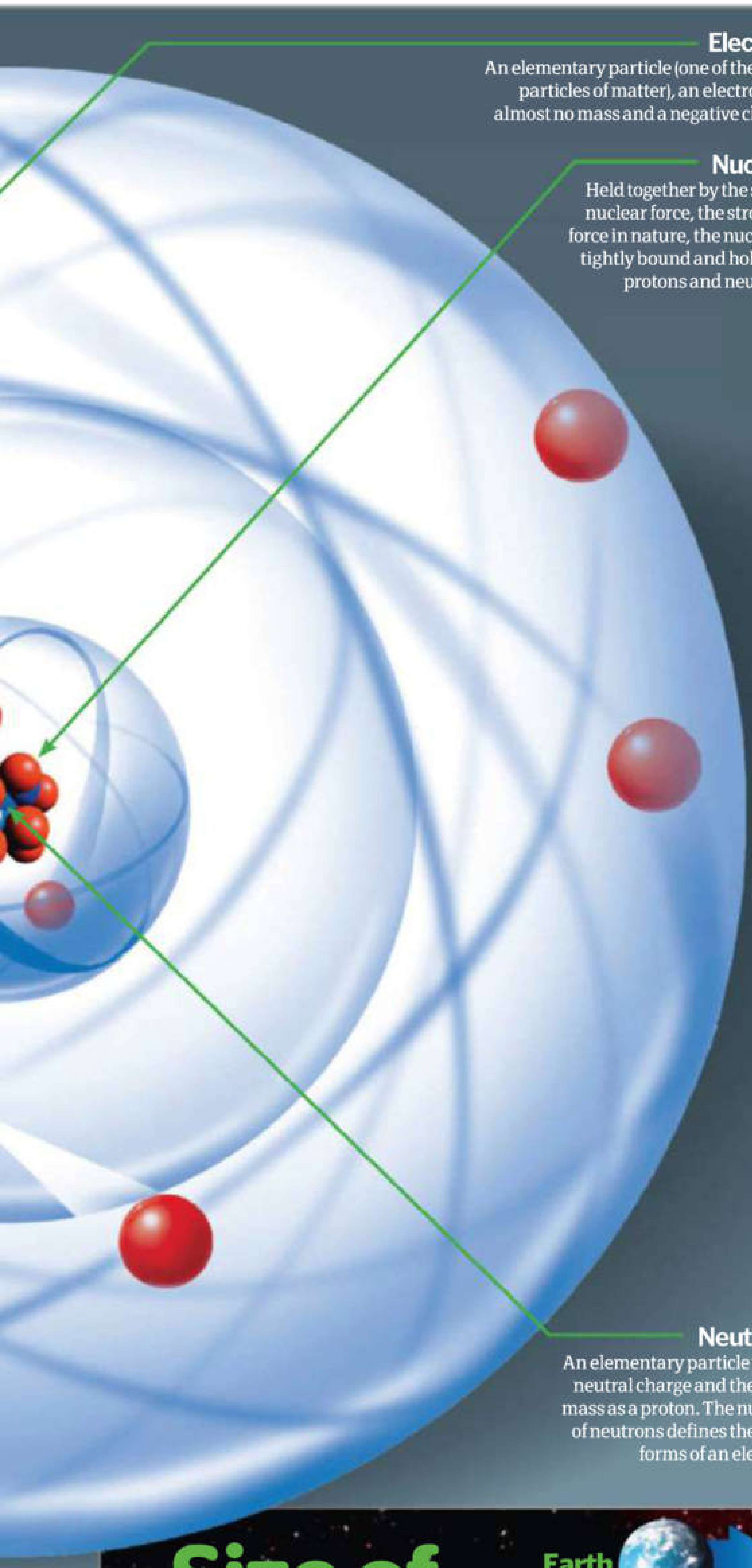


Shell
Each shell can hold a different number of electrons. The first can hold two, the second holds eight, then 18, 32 and so forth.

Protons
A stable elementary particle with a positive charge equal to the negative charge of an electron. A proton can exist without a neutron, but not vice versa.

Quantum jump
An electron releases or absorbs a certain amount of energy when it jumps from one shell to another, known as a quantum leap.

© Science photo library



Electron
An elementary particle (one of the basic particles of matter), an electron has almost no mass and a negative charge.

Nucleus
Held together by the strong nuclear force, the strongest force in nature, the nucleus is tightly bound and holds the protons and neutrons.

Neutrons
An elementary particle with a neutral charge and the same mass as a proton. The number of neutrons defines the other forms of an element.

Power of the atom

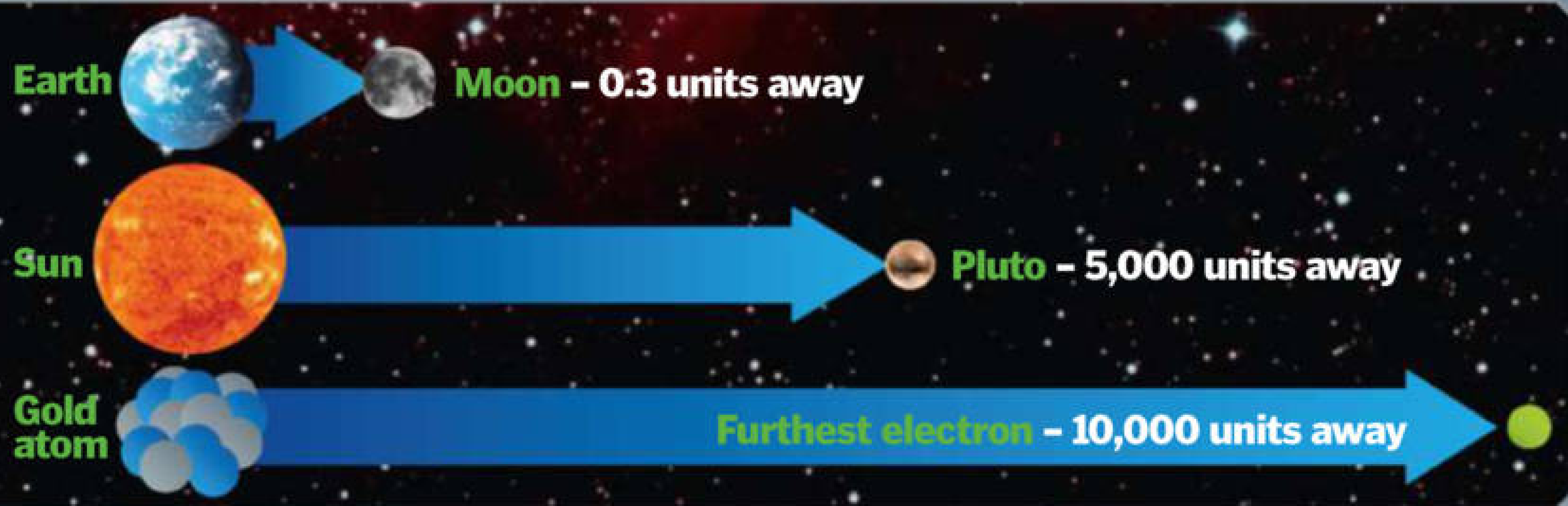
Atomic bombs are notorious around the world for their devastating power. By harnessing the energy in the nucleus of an atom, atomic bombs are one of the most powerful man-made weapons. In 1939, Albert Einstein and several other scientists told the USA of a process of purifying uranium, which could create a giant explosion known as an atomic bomb. This used a method known as atomic fission to 'split' atoms and thus release a huge amount of energy.

The only two bombs to ever be used in warfare were a uranium bomb on Hiroshima and a plutonium bomb on Nagasaki in 1945 at the end of World War II. The effects were frighteningly powerful, and since then no atomic bomb has ever been used as a weapon.

Early atomic bomb tests showed the raw power of the atom

Size of an atom

If the solar system were shrunk to the size of a gold atom, the distance from the Sun to Pluto would be half the distance from the nucleus of the gold atom to its furthest electron. One unit here is defined as the width of a gold atom.



Moon / Pluto / background © NASA

Explore a nuclear reactor's core

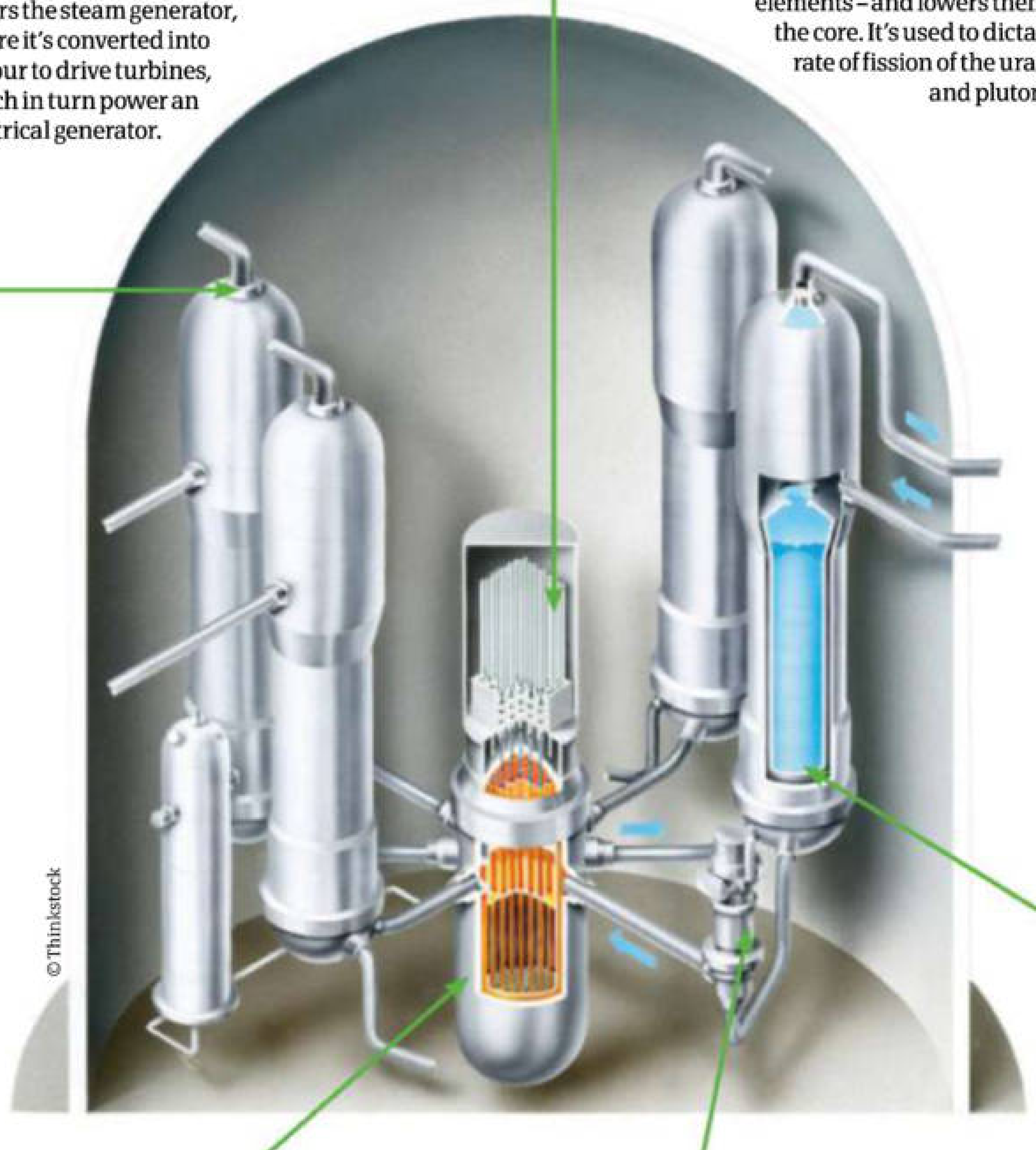
What goes on within the core and why does it glow?

This image shows a nuclear reactor's core surrounded by Cherenkov radiation, which gives it the characteristic blue glow. Cherenkov radiation is a unique phenomenon where particles that are electromagnetically charged – such as electrons – and emitted from a nuclear reactor's core travel faster through its coolant (pressurised water) than the phase velocity of light. This process causes the particles to polarise the water molecules, which then proceed to rapidly descend back to their ground state, expelling photons – hence the perceived blue-white illumination – and intensifying observed radiation levels. As such, the intensity of the core's fission events is directly related to the intensity of its generated Cherenkov radiation.

For a closer inspection of a core's main features and processes, check out the 'Inside a nuclear reactor' boxout below.

Inside a nuclear reactor

What are the main components?



© Thinkstock

1. Steam generator
Heated water from the core enters the steam generator, where it's converted into vapour to drive turbines, which in turn power an electrical generator.

2. Control rod mechanism
This holds the control rods – neutron-absorbing bars of chemical elements – and lowers them into the core. It's used to dictate the rate of fission of the uranium and plutonium.

3. Core
The core is filled with bundles of nuclear fuel rods, with each bundle consisting of 200-300 rods. Typically a reactor has 80-100 of these bundles.

4. Water pressuriser
The water pressuriser receives light (ordinary) water and brings it to a high pressure to prevent it from immediately evaporating and turning into steam

5. Pumps
The reactor's pumps push the pressurised water (coolant) around the core, which absorbs heat generated by nuclear fission, and then into the steam generator.

"The core is filled with bundles of nuclear fuel rods, with each bundle consisting of 200-300 rods. Typically a reactor has 80-100 bundles"

New fuel rods are inserted into the core of a nuclear reactor in Essenbach, Germany

© Corbis

Building dem

What does it take to turn solid cement and steel into a waterfall of cascading rubble?

Modern building demolition is an exquisitely choreographed dance of destruction. Dynamite-triggered 'implosions' – where a building collapses in on itself just like a crumbling house of cards – are so violently beautiful that they have even become a spectator sport. Demolition junkies are known to camouflage themselves as shrubs just to get a close-up shot of the carnage.

Blowing up a building is easy, minimising damage to nearby structures is the tricky part. There are tumbling walls and flying debris to worry about, not to mention the earthquake-like vibrations produced by millions of tons of crashing cement and steel. The explosives alone can produce high-pressure shockwaves that shatter windows for miles.

Demolition experts are called blasters ('explosives engineer' lacks a certain punch). They know that the most powerful force on a demolition site isn't the thousands of pounds of dynamite, but the incredible potential energy of gravity. The key to minimising damage and softening the impact of 30 stories of rubble is to use the least amount of explosives possible and let gravity pull the building down in a progressive, 'liquid' collapse.

To trigger a progressive collapse, blasters divide the building into separate vertical columns. They drill thousands of holes in the weight-bearing supports under each column and stuff them with dynamite. The supports are wrapped tightly in chain-link fencing and thick plastic fabric to contain flying debris.

Each stick of dynamite is plugged with a blasting cap that controls the precise timing of the explosion. All of the explosives are connected back to a single detonator by miles of detonator cable. When the blaster yells "Fire in the hole!" he activates the detonator, initiating a series of sharp, popping explosions that obliterate the column supports section by section.

The result is breathtaking. Each column seems to melt to the Earth in a smooth, wave-like motion. The fluid collapse sequence minimises vibrations on the ground and the small, delayed explosions reduce the damaging effects of shockwaves. When the dust settles (which can take 15 to 30 minutes), all that is left is a two-storey pile of rubble, neatly contained within the footprint of the original structure.

The swan song of the Stardust Hotel in Las Vegas before it comes crashing to the ground

© Andrew Ferguson 2007

© Torsten Bätge 2004

olition

1. Detonation
Following the explosion, the building begins its breathtaking descent

© Tannoy 2006

2. Going, going…
Gone. All that is left is a pile of rubble and a cloud of dust

© Tannoy 2006

How implosions work

How the charges are placed within a building's structure in order to collapse it in on itself

Kit list

To demolish a ten-storey building you will need:

Conventional demolition equipment: Enough shovels and sledgehammers to gut the bottom floors of non-weight-bearing walls.

Two different kinds of explosives: Regular nitroglycerin-based dynamite for concrete supports and a high-velocity explosive called RDX for slicing through steel beams. In total, around 180kg of explosives.

Blasting caps: Thousands of small detonators attached to individual sticks of dynamite to precisely time the detonation.

Hundreds of metres of fencing: And geotextile fabrics to wrap around concrete supports stuffed with dynamite.

Detonating cord: Miles of cable to connect each stick of dynamite to a single detonator control.

Detonator control: This has two buttons: one to charge the electrical detonation and one to fire the explosives.

Years of experience: Blueprints can only tell you so much. Expert blasters rely on a storehouse of hands-on knowledge as they work.

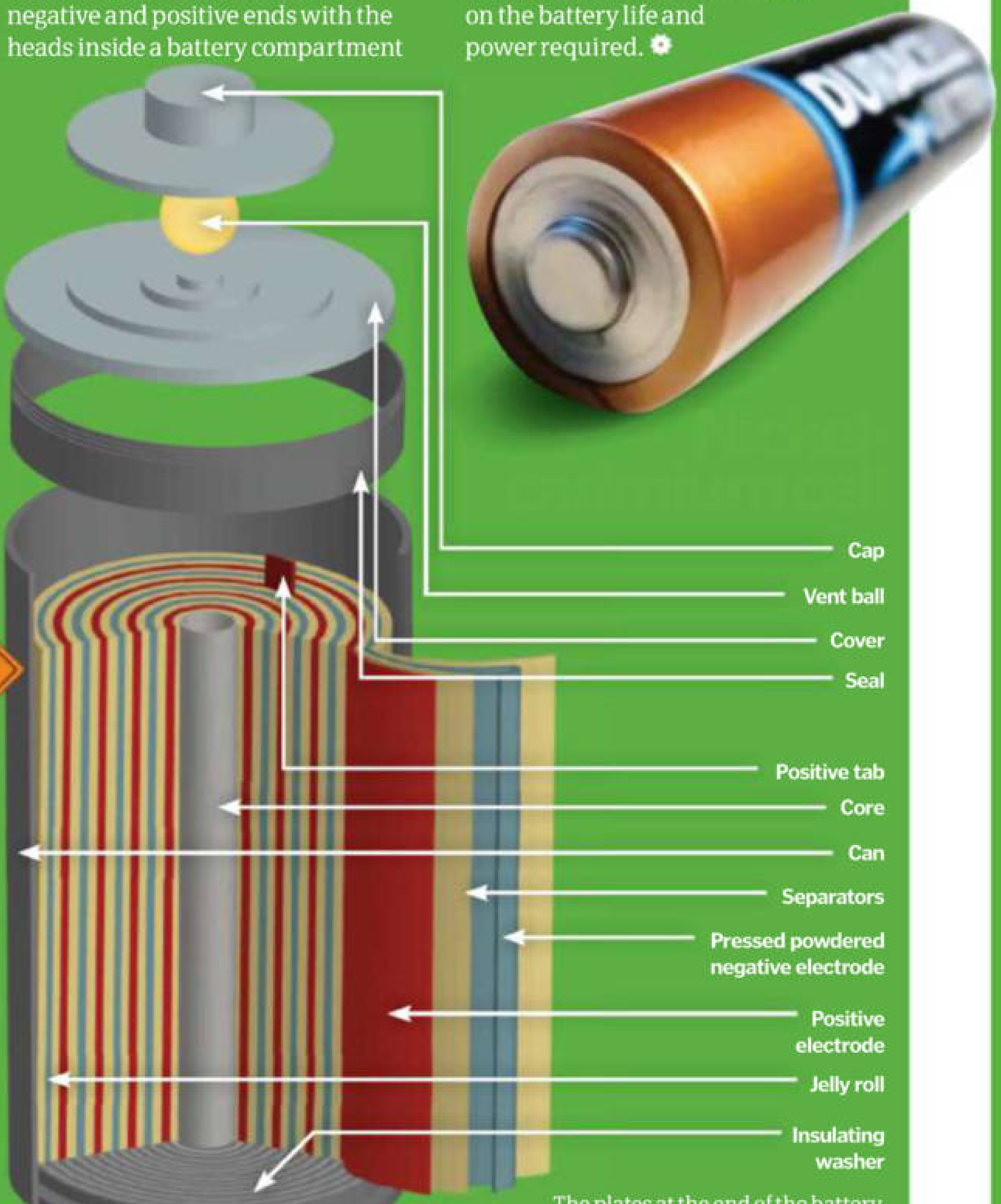
How chemicals power batteries

There's a good reason why battery power is called 'juice'

Batteries are everywhere – in your car, your computer and even your cooker. While some are rechargeable and some are disposable, they all work on the same basic principle.

A battery has two poles labelled + and –. They provide more than a handy guide as to which way up the battery goes in your TV remote. Electrons are produced inside the battery and when it's inert they stay on the negative end. Connect the negative and positive ends with the heads inside a battery compartment and the electrons move to the positive end, producing electrical power.

But where do those electrons come from? The reaction of substances inside the battery produces them. Common elements used are nickel and cadmium, but zinc is also popular. The battery 'plates' are each made up of a different element and when connected they react with the electrolyte paste or 'juice' within the battery, producing electrons. Different substances are used depending on the battery life and power required.



The plates at the end of the battery react with the substance inside

EXPLOSIVES

Man has created many different types of explosives over the past 1,000 years, deploying them in warfare, industry and society

Explosions are characterised by three factors: a rapid increase in volume, the generation of high temperatures and an extreme release of energy. In addition, every explosion generates a shock wave that varies depending on the explosive's detonation velocity.

The four main properties of explosions are force, velocity, heat and fragmentation. An explosion's force is its physical impact on the environment, often increased through a warhead's shaped charge. An explosion's force when magnified in a shaped charge can gauge impact craters, tear through the armour of military vehicles and puncture buildings.

An explosive's detonation velocity is the rapidity of the expansion of its volume (gases mainly) post detonation. Typically, the greater the detonation velocity the higher the relative effectiveness (RE) of the explosive, with a direct correlation between velocity, pressure and generated heat. So, the greater the velocity the greater the heat and damage.

Heat, an effect and also the cause of an explosion's high pressures, is its ability to liberate its exothermic material's elements at a certain temperature. Coal, for example, is very good at doing this at a high temperature in an exothermic reaction, albeit at such a slow rate that it can't be used as an explosive (which is why we use it for fires). Nitroglycerin (the chemical base of explosives such as dynamite) produces five times less heat than coal but has the necessary rapidity in liberation for an explosion to be caused.

Finally, almost all explosions are subject to fragmentation – the accumulation and projection of particles as a result of its detonation. Fragmentation is proportional to the explosion's generated shock waves and detonation velocity, with supersonic shock waves producing far more fragmentation than subsonic varieties. Fragmentation increases an explosion's potency ten-fold ✿

The history of explosives

Chart the rise of man-made explosives over the centuries

800AD

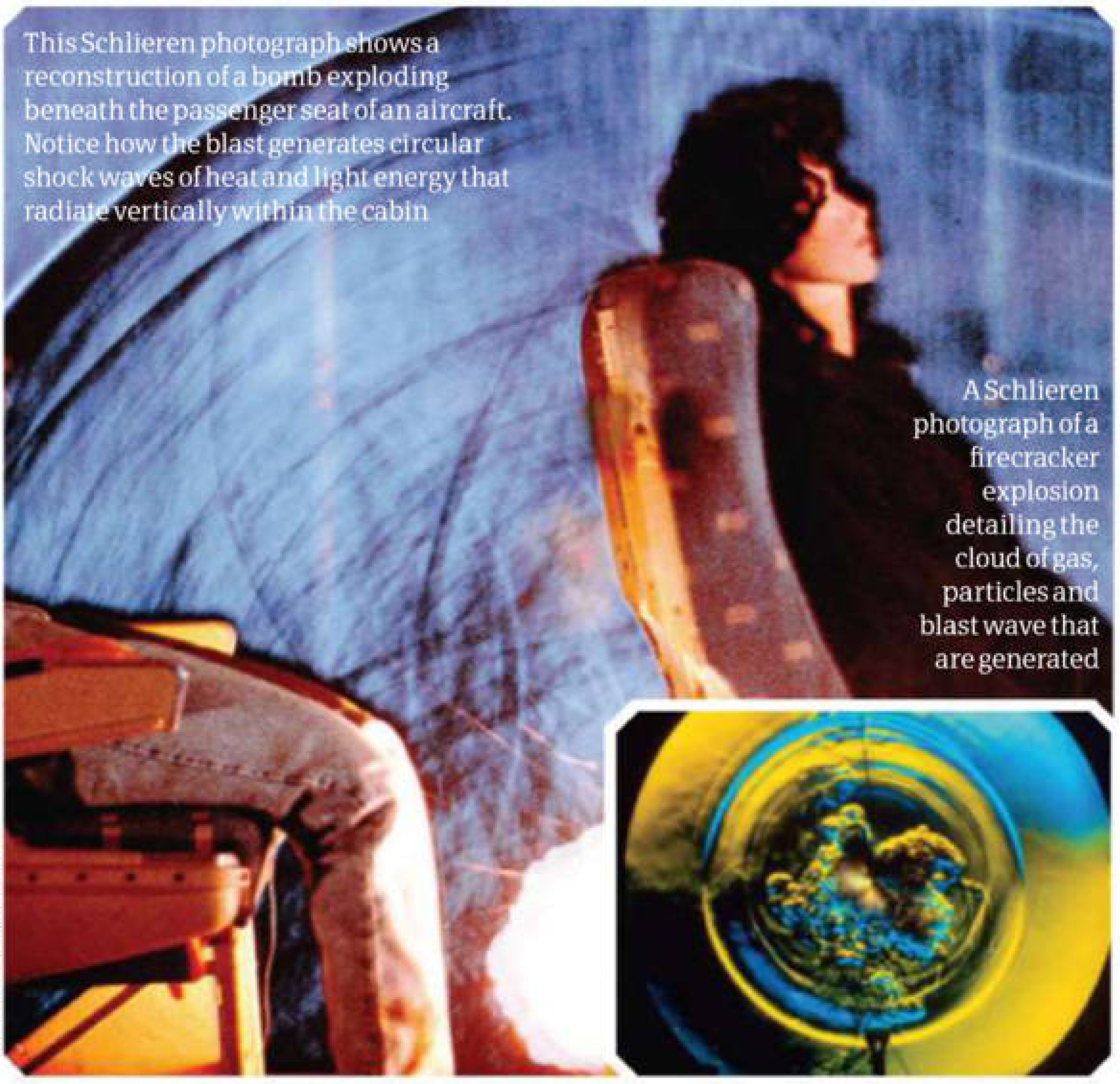
Ancient Chinese: The ancient Chinese are credited with the creation of early explosives – which were crude black powders – used in rockets and fireworks.

1300AD

European gunpowder: By the 1300s, the knowledge of the East had reached Europe and a new era of explosive warfare ensued, relegating suits of medieval armour to museums.

1846AD

Nitroglycerine: More powerful than black powder, nitroglycerine paved the way for the creation of dynamite and other explosives.



This Schlieren photograph shows a reconstruction of a bomb exploding beneath the passenger seat of an aircraft. Notice how the blast generates circular shock waves of heat and light energy that radiate vertically within the cabin

A Schlieren photograph of a firecracker explosion detailing the cloud of gas, particles and blast wave that are generated

© Science Photo Library

Why are explosions deadly?

Capable of breaking the physical threshold of human tissue, explosions claim many lives

Explosions are deadly for a variety of reasons. The basis of any explosion is the rapid burning and decomposition of a material, a process that creates a large amount of heat, pressure and gas in a short amount of time. All these factors can have an effect on humans, as their physical thresholds to withstand the various forces and chemicals in play is easily broken. For example, the heat generated by an explosion of HMX reaches thousands of degrees Celsius in a matter of seconds, something that the skin of a human – which would be subjected to third-degree burns – could not withstand, with the skin tissues and structures being destroyed.

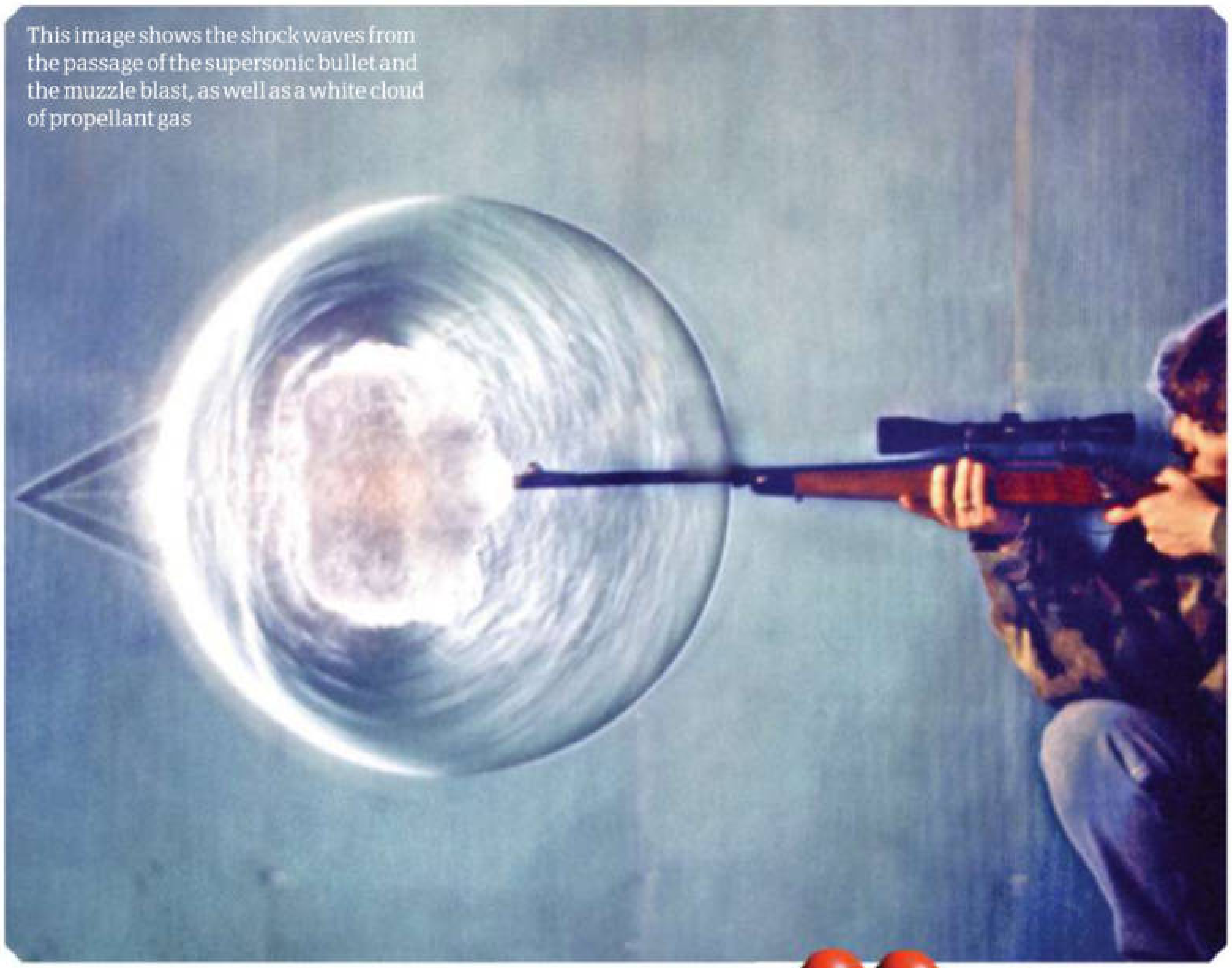
The force and velocity of the detonation is equally as deadly. The shock wave created by an explosion carries tremendous amounts of energy and can easily project objects of such light weight hundreds of feet. Fragmentation – the shattering of explosive casing and material in an explosion's immediate vicinity – in supersonic explosions can also cause severing and puncturing to human tissue. In addition, the force of any explosion is often increased if it is a consequence of the detonation of an explosive device. This is because many warheads, mortars, rockets, shells and bombs have shaped charges, as demonstrated in the example of C-4, a type of plastic explosive which is based on cyclotrimethylene-trinitramine (RDX). C-4 is particularly deadly because it can be moulded into various shapes to increase its destructive potential.

Gunpowder

Since its invention by the ancient Chinese, gunpowder has been one of the most used explosives on Earth

Gunpowder, unlike other modern explosives, is classified as a low explosive – an explosive that undertakes subsonic combustion – as it deflagrates slowly. For this reason, despite its creation over 1,000 years ago, it was still used as the explosive mechanism in guns all over the world up until the 20th Century, providing enough energy to propel a bullet out of a muzzle, but not enough to break the weapon and injure the user (of course, backfires and jams lead to bad injuries).

Modern rifle cartridges – the combination of a bullet, case, powder and primer – such as the one fired in the accompanying image, use smokeless powders (they are not actually smokeless, however, just considerably less so than conventional black powder), as their combustion efficiency is greatly increased, allowing rounds to be fired with less explosive. Further, smokeless powder does not leave heavy fouling (unwanted residue materials) within the weapon, allowing for semi and full automatic rifles to operate cleanly and efficiently.



This image shows the shock waves from the passage of the supersonic bullet and the muzzle blast, as well as a white cloud of propellant gas

1863AD

Trinitrotoluene: Trinitrotoluene or TNT for short, was created by German chemist Joseph Wilbrand in 1863. It is now used as the modern benchmark for all other explosives.

1950AD

C-4: A common type of plastic explosive due to its easy handling, C-4 is based on the explosive RDX and provides massive, yet refined, damage.

2000AD

Octanitrocubane: With performance roughly 25 per cent greater than HMX, this is currently considered the most powerful non-nuclear explosive on the planet.

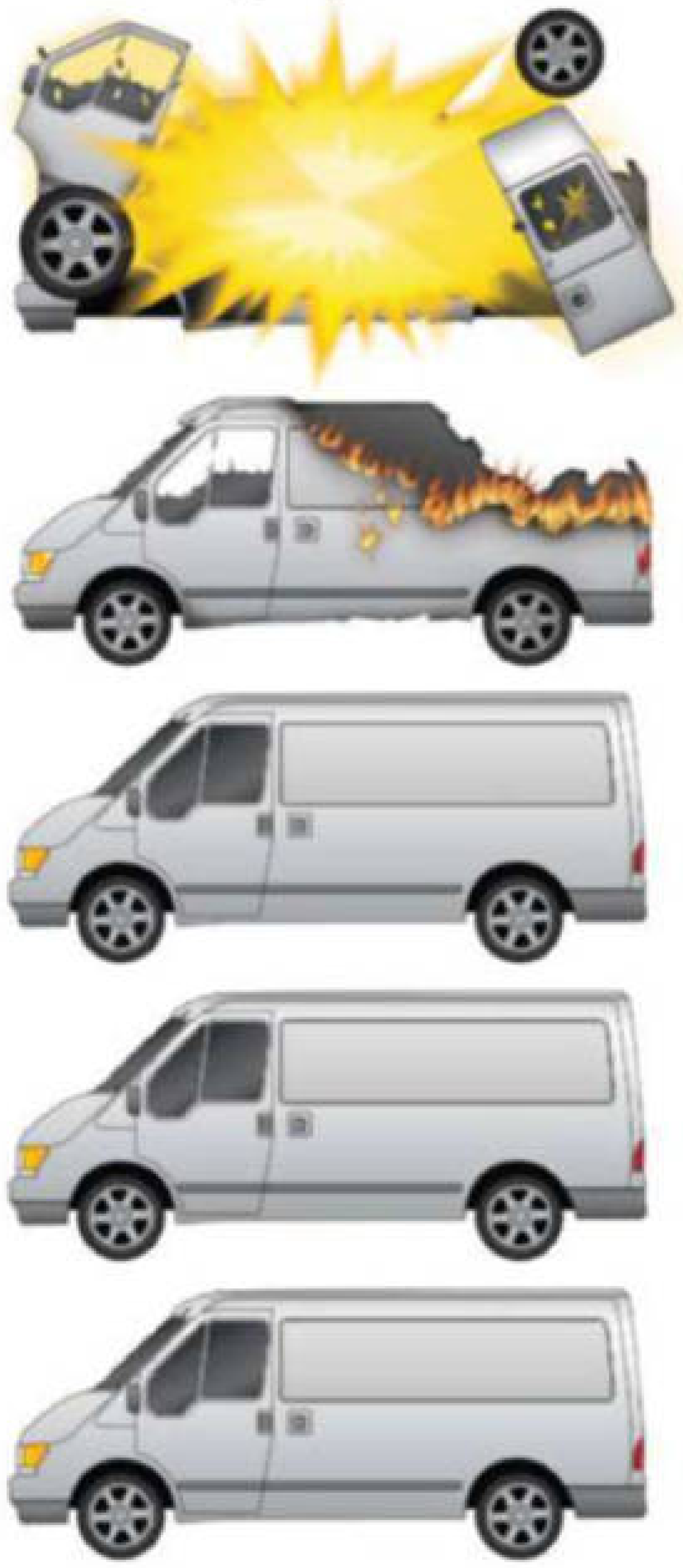
What are the most powerful explosives?

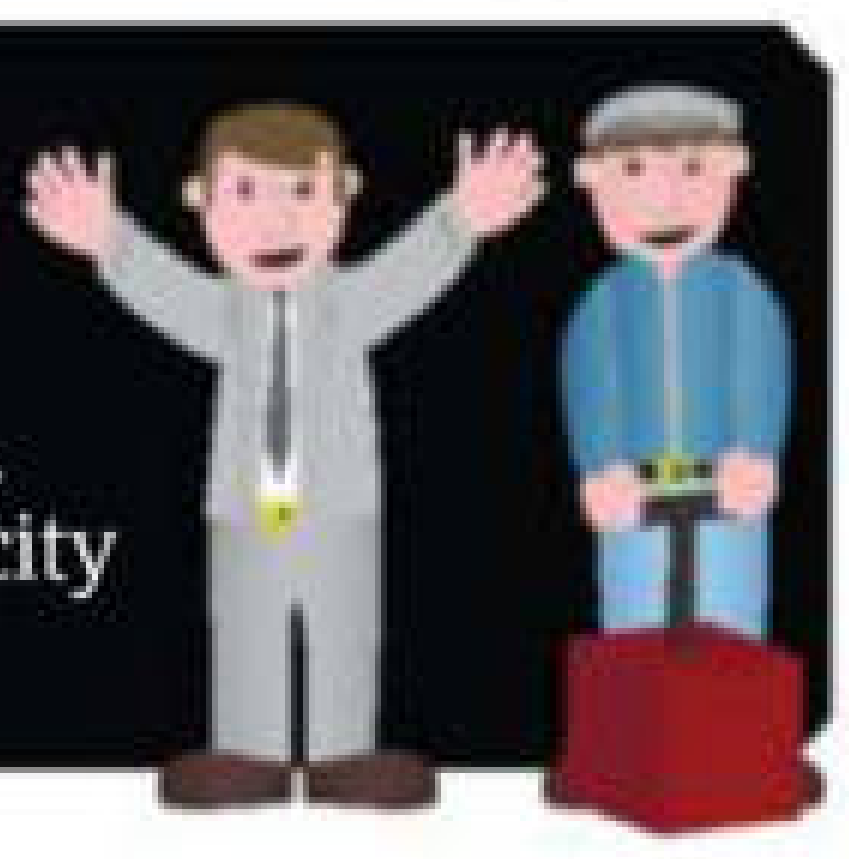
Trinitrotoluene

The first real breakthrough for explosives post gunpowder, trinitrotoluene is one of the most commonly used explosives on Earth. It was formed in 1863 and has an RE (relative effectiveness) factor of 1.00.

Molecular formula:

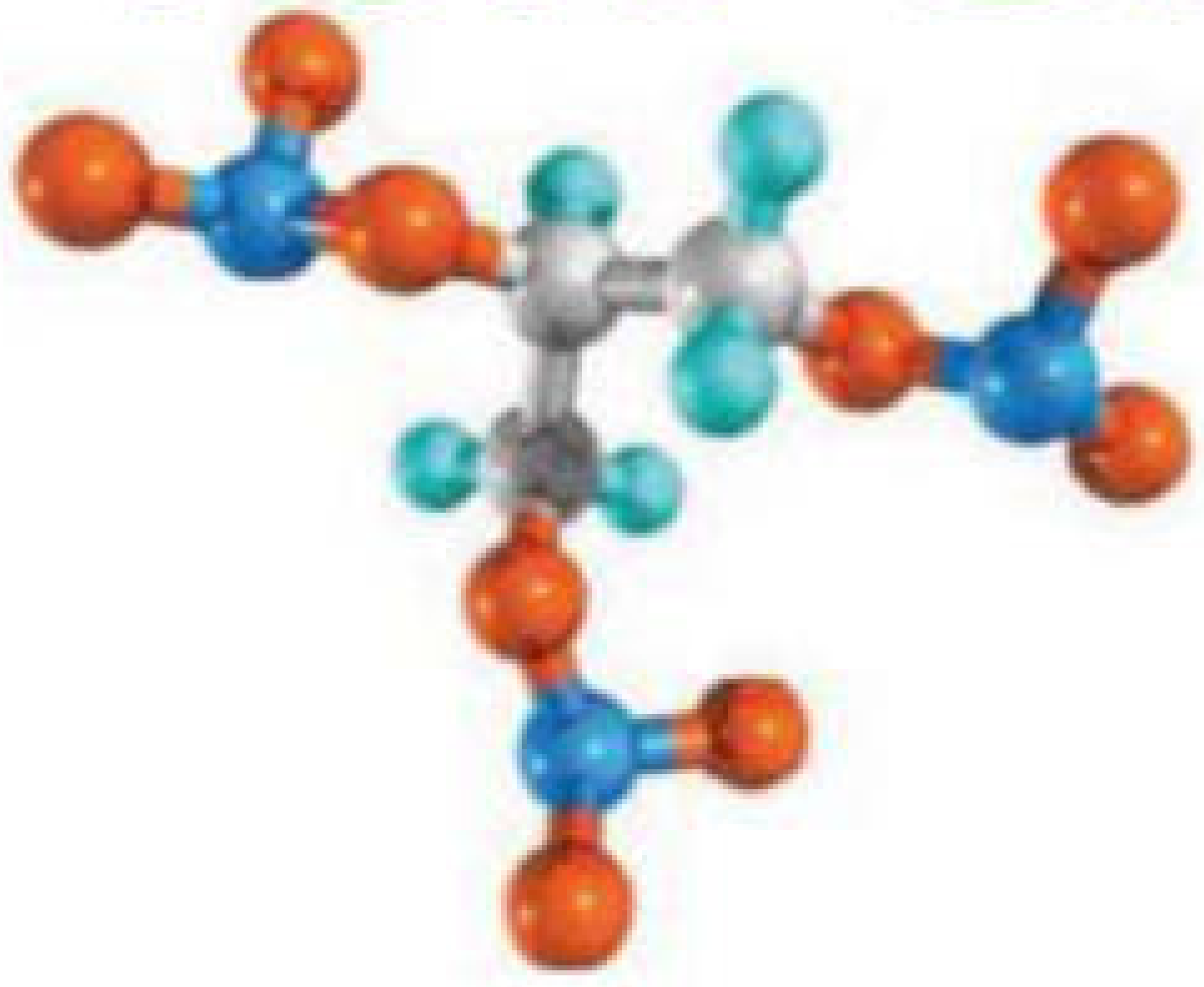
$C_6H_2(NO_2)_3CH_3$





1.5/5

Small explosion. Detonation velocity of 6,900m/s.

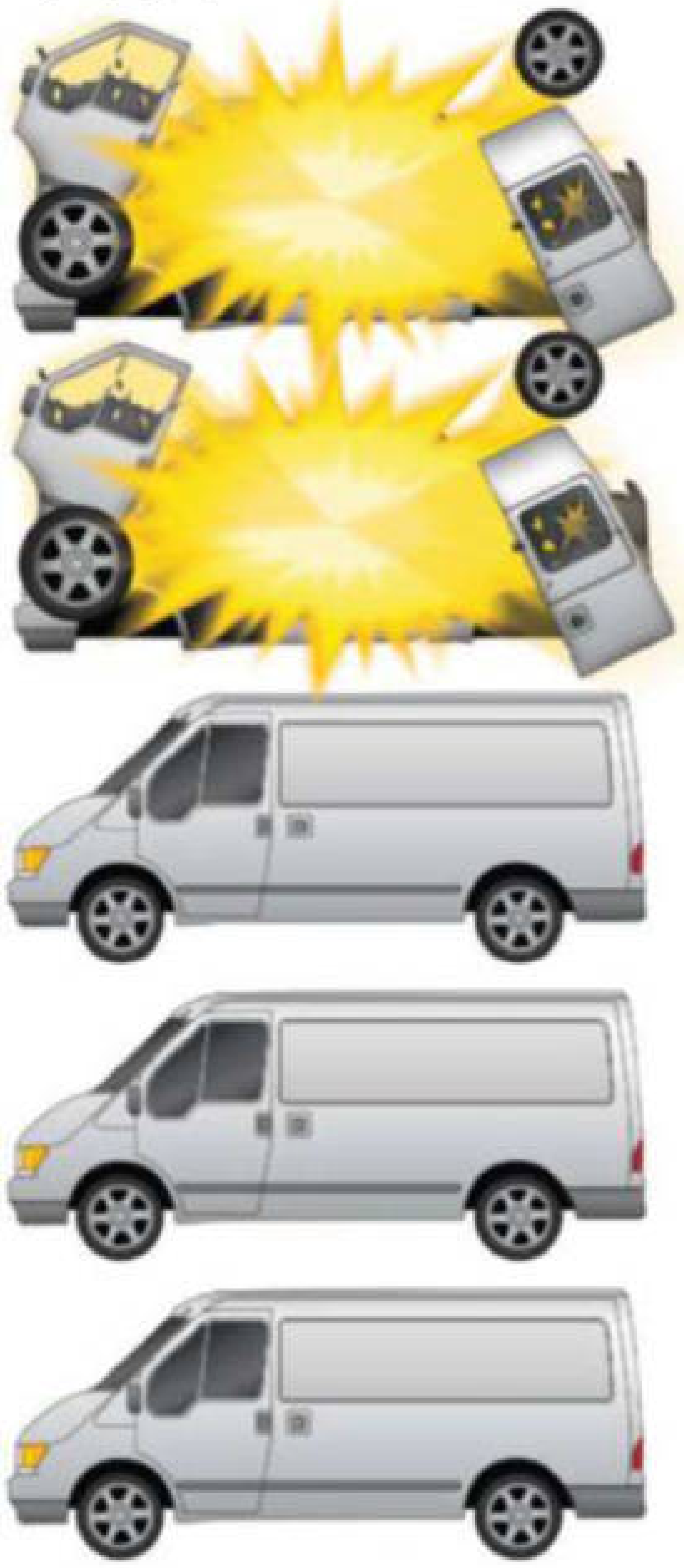


Dynamite

Based on nitroglycerin, dynamite has 60 per cent greater energy density than TNT. It was first created in 1867 by renowned German chemist Alfred Nobel and has an RE factor of 1.50.

Molecular formula:

$C_3H_5N_3O_9$



2/5

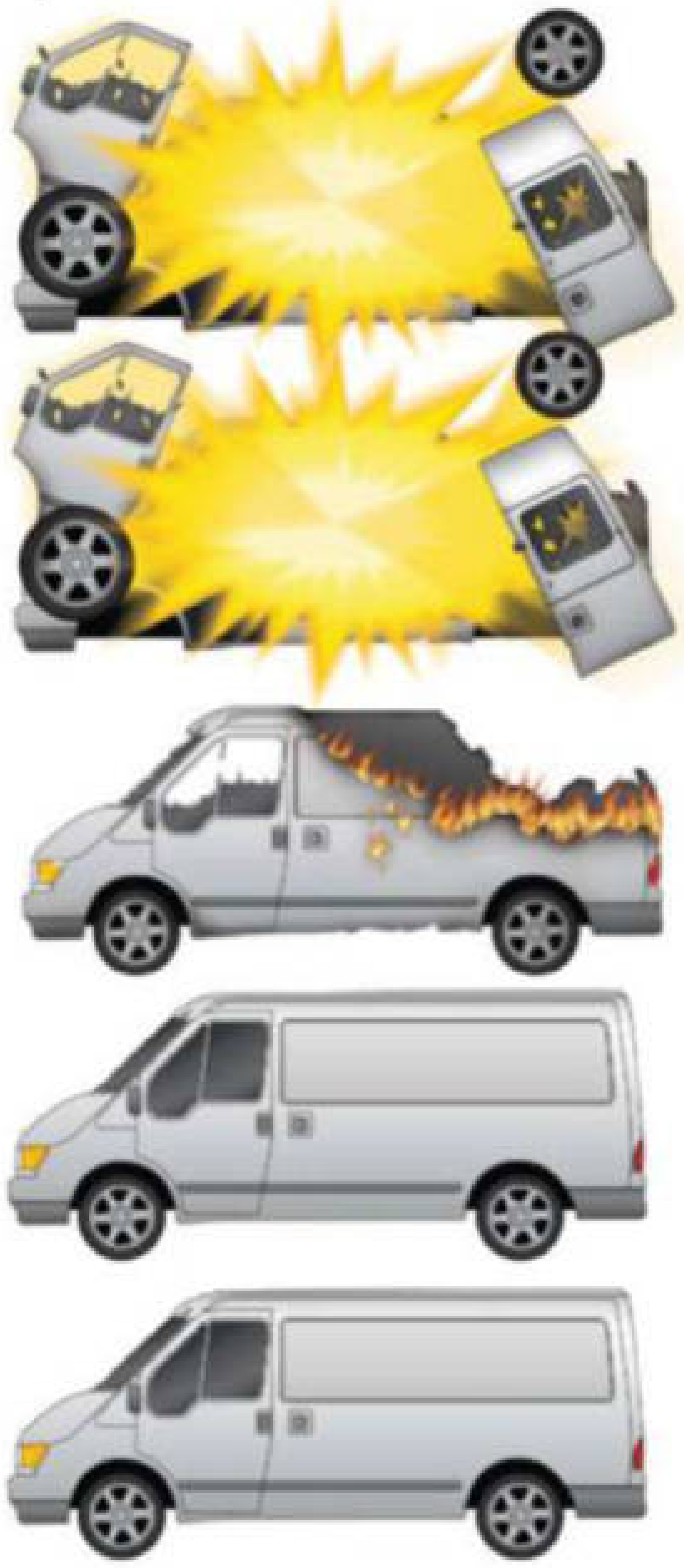
Modest explosion. Detonation velocity of 7,700m/s.

C-4

Based on the explosive RDX, C-4 is the most famous plastic explosive used today. It is easily moulded into any shape (excellent for shaped charges) and has a high detonation velocity. It has an RE factor of 1.34.

Molecular formula:

$C_3H_6N_6O_6$



2.5/5

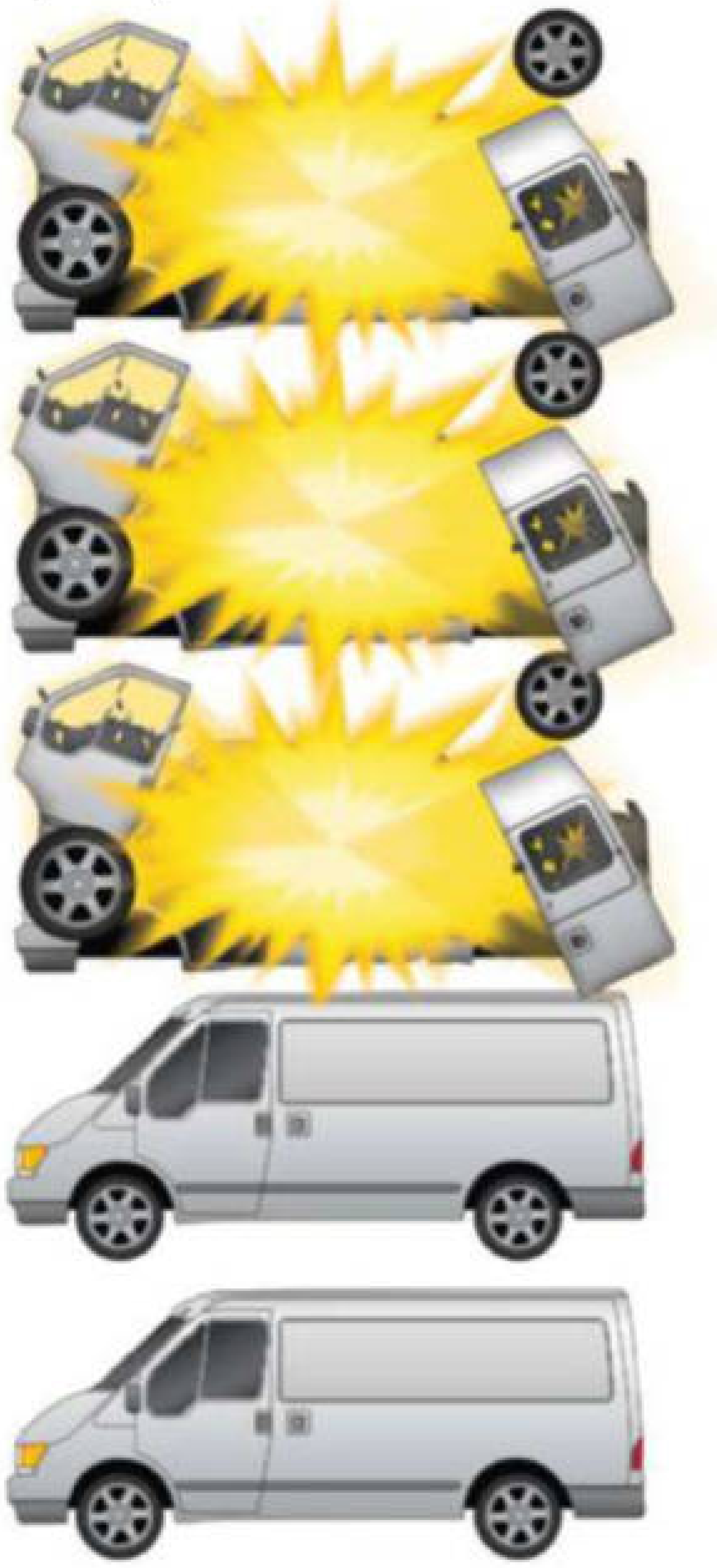
Large explosion. Detonation velocity of 8,040m/s.

Semtex

Another brand of plastic explosives that is used mainly in commercial and industrial applications, Semtex is a mix of RDX and PETN. It is brick-orange in colour and has an RE factor of 1.66.

Molecular formula:

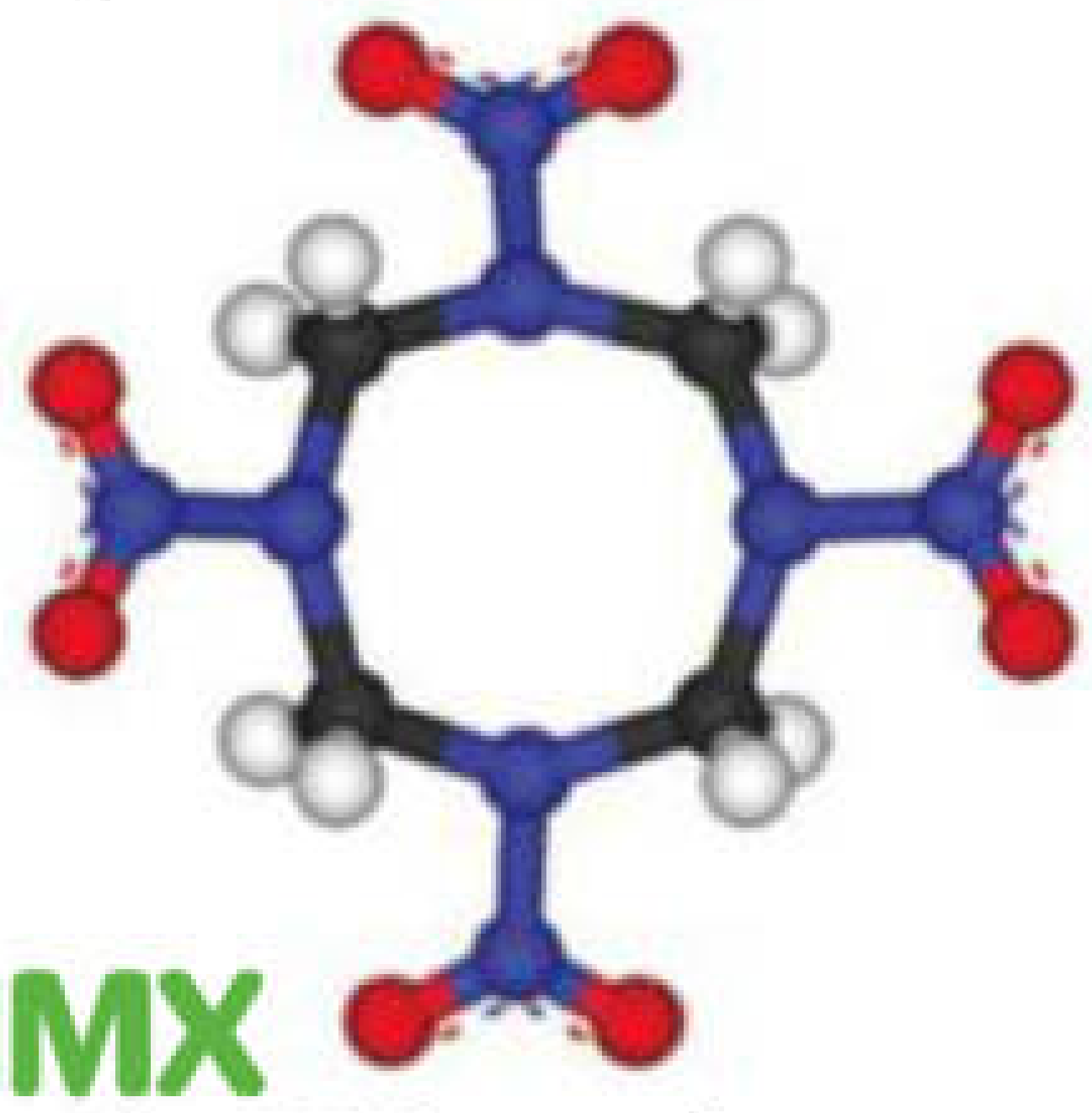
$C_5H_8N_4O_{12}$



3/5

Great explosion. Detonation velocity of 8,420m/s.

A visual guide to the six most powerful non-nuclear explosives on the planet

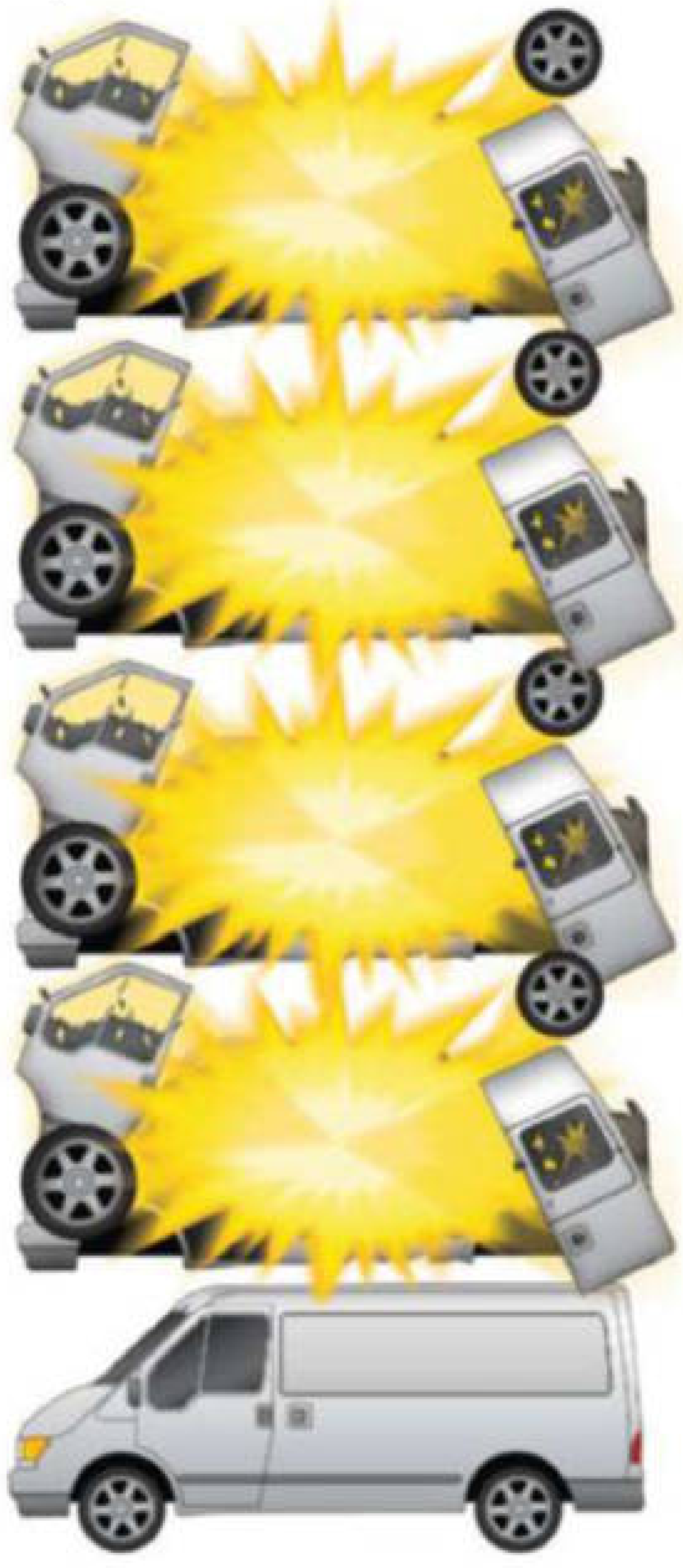


HMX

Related to RDX but much more explosive, HMX is a nitroamine high explosive. Difficult to manufacture, it is only used for specialist military purposes, such as a nuclear bomb detonator. It has an RE factor of 1.70.

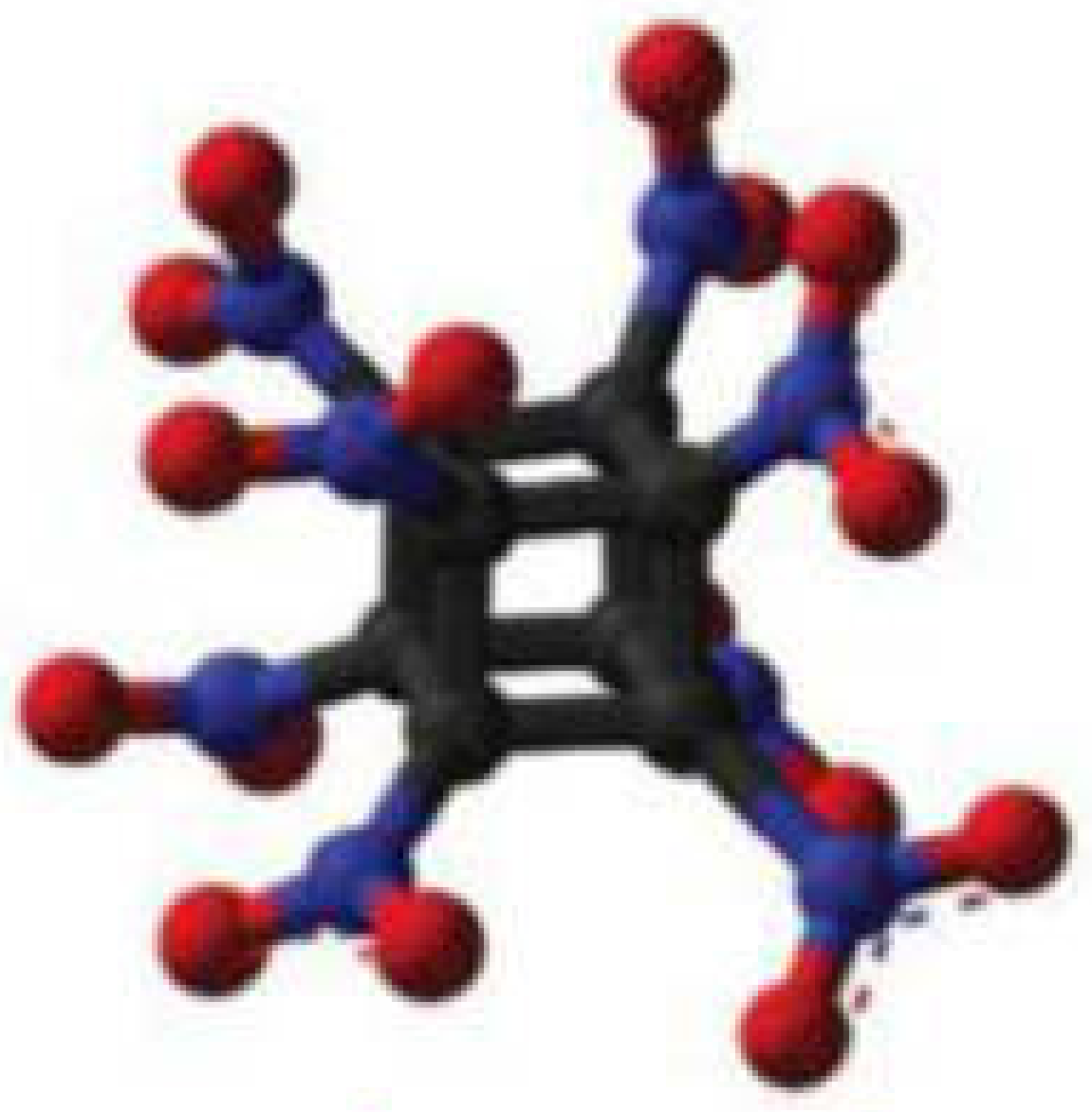
Molecular formula:

$C_4H_8N_8O_8$



4/5

Massive explosion. Detonation velocity of 9,100 m/s.

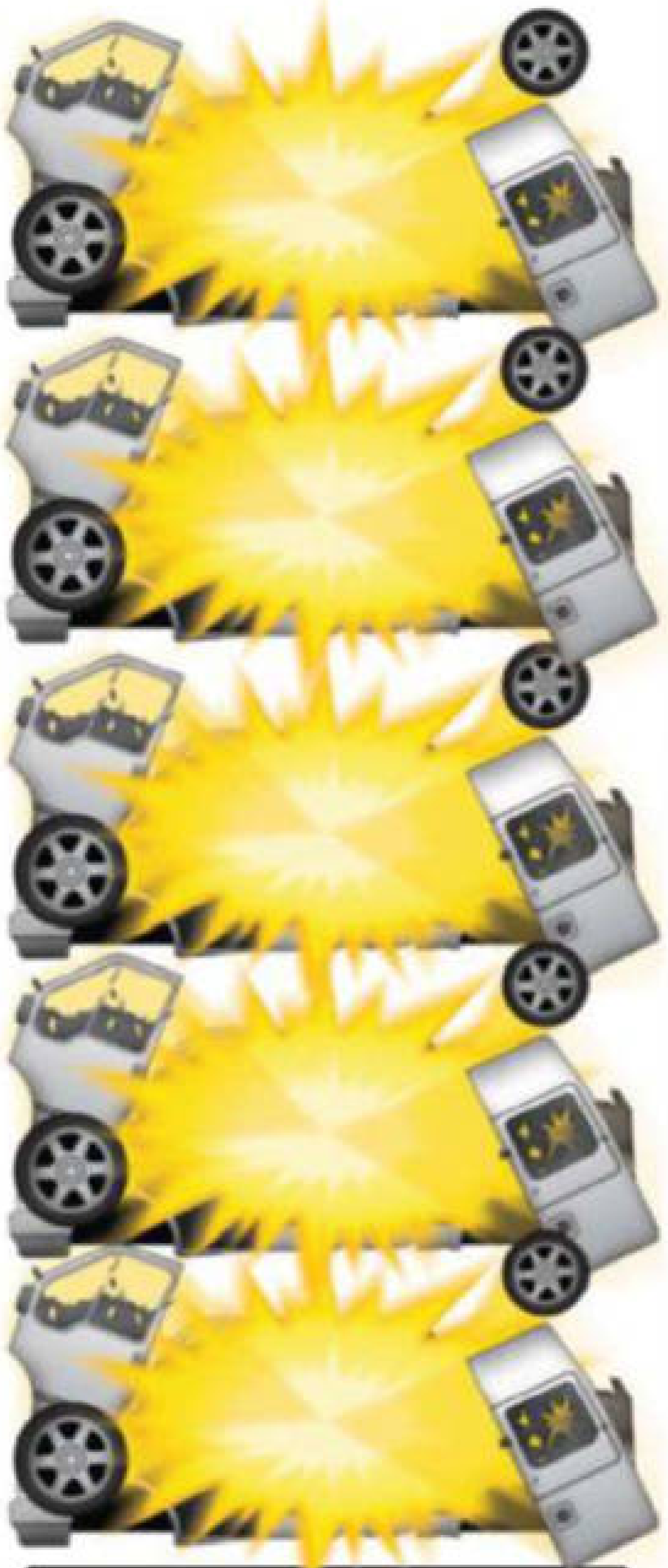


Octanitrocubane

The most explosive chemical structure on Earth, Octanitrocubane has 25 per cent greater performance than HMX. It was synthesised at the University of Chicago in 1999 and has an RE factor of 2.70.

Molecular formula:

$C_8(NO_2)_8$



5/5

Epic explosion. Detonation velocity of 10,100 m/s.

Explosions in nature

Explosions are not always man-made, with many natural examples visible over the Earth and in space

Organic – Many explosions are caused by plants and trees when subjected to hot and volatile conditions. For example, the Eucalyptus tree – which is predominantly found in Australia, New Guinea and Indonesia – is often prone to spontaneous combustion in periods of sustained heat and dry conditions. This is caused by the tree's high oil content (ie Eucalyptus oil) that rises above the bush as vapour when heated sufficiently creating a characteristic haze in dense forested areas. This oil, in both liquid and vapour forms, is incredibly flammable and if environmental pressure and heat reach critical levels, is prone to combust suddenly. This factor is severely exacerbated when a forest fire passes into Eucalyptus-heavy areas, as the resulting explosions and general flammability of the tree's bark carries and also generates fire quickly.

Volcanic – Maybe the most obvious example of a natural explosion, volcanoes cause explosions when magma, which has risen to the Earth's surface, releases large amounts of accumulated dissolved gases into the atmosphere. This reduction in pressure above ground causes the gas to be separated from the magma and rapidly increase in volume, sending massive clouds of volcanic dust and particles spiralling into the atmosphere. Further, if a volcano's resulting magma flow reaches a water source, such as the ocean, then further steam-based explosions may be caused when the high-temperature flow meets the cold water, rupturing sections of coastline.

Stellar – The largest natural explosion currently known in the universe is that of a supernova, the resulting explosion that follows a dying star. Supernova explosions are ridiculously powerful and send the remnants of the star's material screaming out through space at a velocity up to 30,000km/s – that is ten per cent the speed of light – in a vast shock wave. Supernovas can be caused in a variety of different ways, however the most common is when the core of an aging star ceases to generate nuclear fusion, collapsing in on itself under the effects of gravity and expelling its outer layers as it releases its gravitational potential energy. During its short explosion (due to its size this would last several weeks or months) the amount of radiation of a supernova can total the entire amount it has ever radiated over its whole life span.

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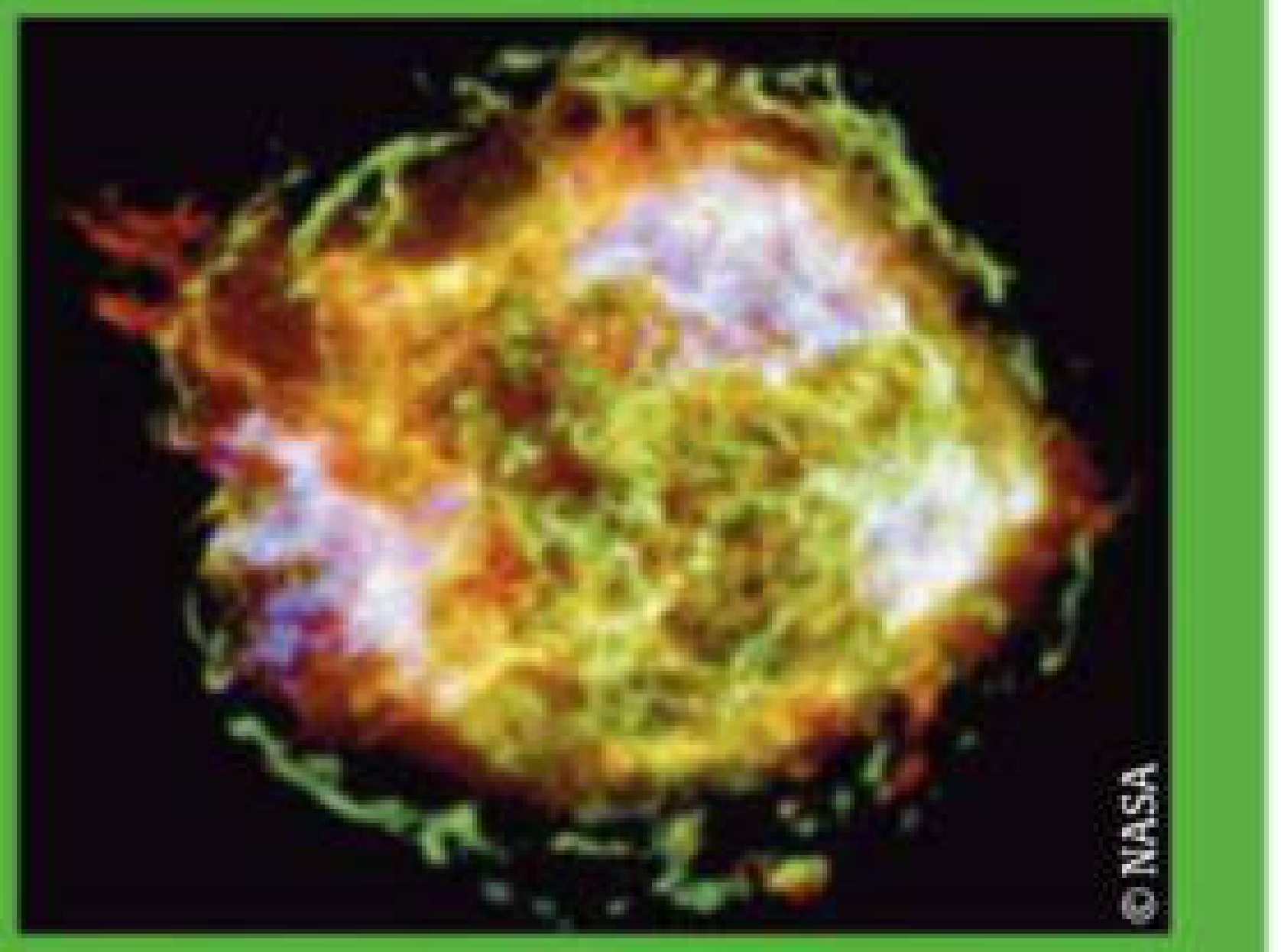
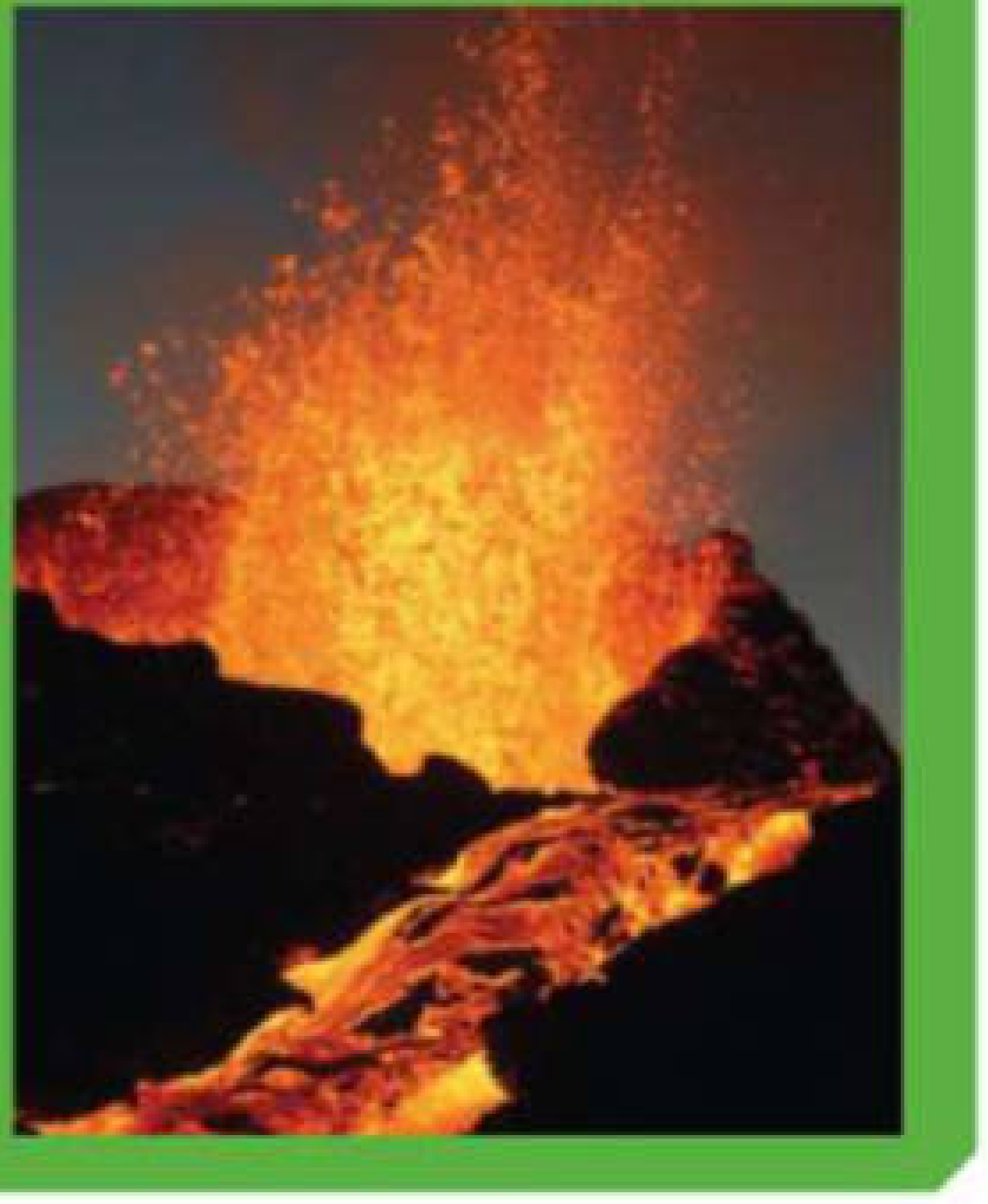


© NASA



THE SCIENCE OF FIRE

From its atomic properties to what determines its colour, we explore the fundamentals of the element that can sustain life as easily as it can destroy it

Most of us encounter some form of fire every day, whether we're basking in the rays of the Sun, lighting a match or cooking food. It's likely that early man 500,000 years ago didn't quite have the method of creating fire nailed down, instead relying on natural occurrences such as lightning to start a fire which they would then store underground in hot ashes for later use.

Nowadays we use fire on a much more controlled and regular basis, but the complex physics and chemistry behind how it works are the same as they have always been. From heat intensity to combustion, this article will tell you all about the science behind this powerful phenomenon essential to life.

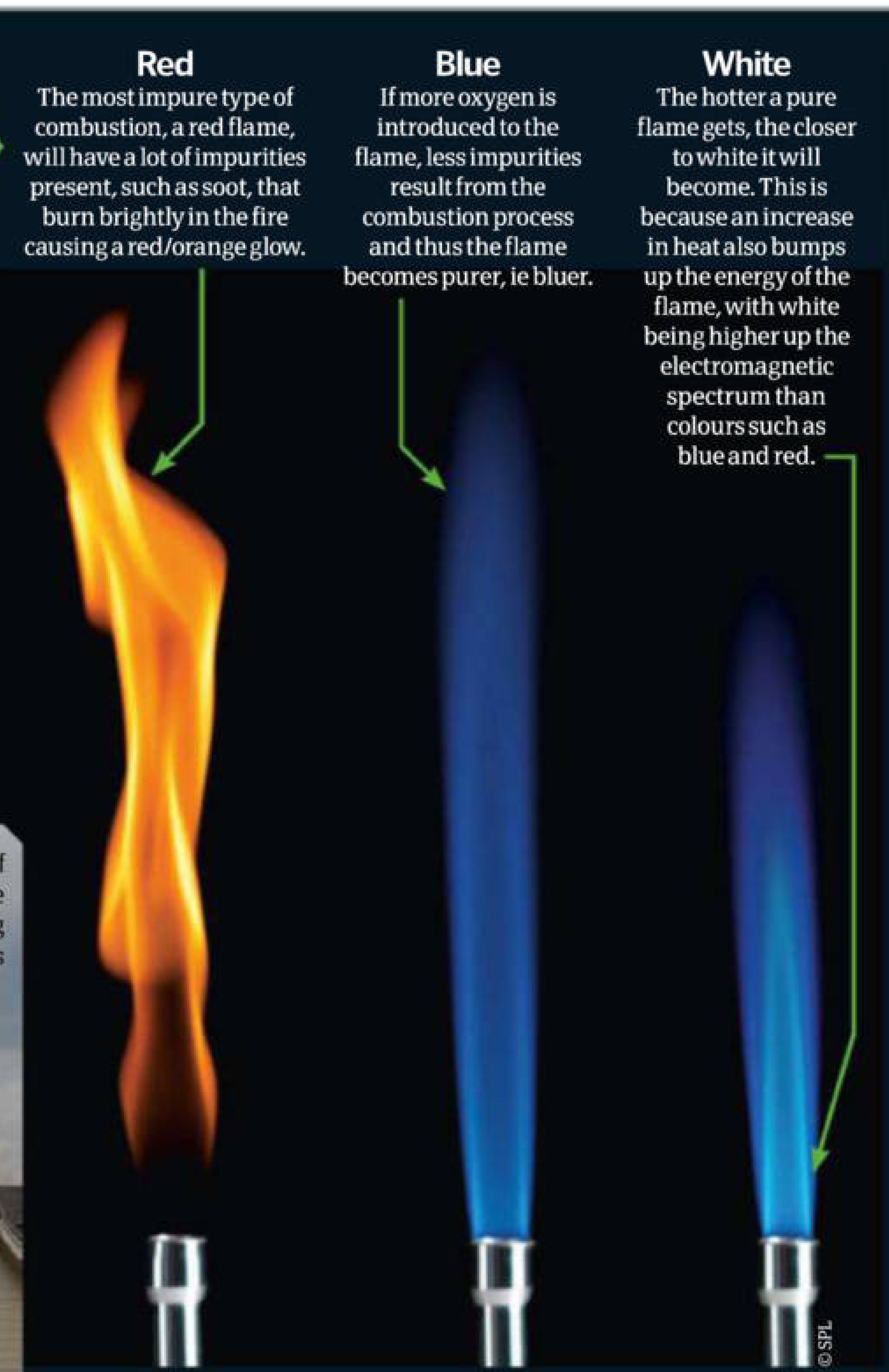
We'll start small – with what's going on at an atomic level. The process of creating fire, known as combustion, is basically oxidisation occurring very quickly. When a metal such as steel rusts, it is oxidising but not at a fast enough rate to generate fire. To understand how something can oxidise rapidly enough to produce a flame, we need to understand why the atoms want to bond in the first place.

Generally, fire is the burning of an organic substance which contains lots of carbon. Carbon atoms want to bond with oxygen atoms, but they need a little push in order to do so. If we briefly consider photosynthesis, the energy of the Sun is required to split carbon and oxygen atoms apart. However, when they're apart, they want to immediately snap together again, but require a little encouragement. Imagine a ball trying to roll up a hill, which has a deep hole at the top. If the ball is rolled gently against the slope, it doesn't have enough energy to reach the peak and fall into the hole,

RED-HOT TO WHITE-HOT

Why do standard flames vary in colour from orange to blue?

The colour of a flame is dictated by the blackbody radiation of the substance that is burning and the oxygen supply to the flame itself. Fire is produced by oxidisation, but as a by-product of the combustion process impurities are often created. The more oxygen present, the less impurities there are. It is these impurities that glow red when hot, causing the fire to burn that well-known orange colour. In addition, the hotter a flame is, the whiter it will become. This is because as things burn at a hotter temperature they move further along the visible spectrum to higher-energy colours such as white, hence the phrase 'white hot'. As a result, white hot is technically hotter than 'red hot'.



Red The most impure type of combustion, a red flame, will have a lot of impurities present, such as soot, that burn brightly in the fire causing a red/orange glow.

Blue If more oxygen is introduced to the flame, less impurities result from the combustion process and thus the flame becomes purer, ie bluer.

White The hotter a pure flame gets, the closer to white it will become. This is because an increase in heat also bumps up the energy of the flame, with white being higher up the electromagnetic spectrum than colours such as blue and red.

© SPL

Fire is a devastating force of nature that can reduce entire buildings to smouldering wrecks in mere minutes

The Derweze Crater in Turkmenistan is a natural occurrence of methane combustion and has been ablaze for over 40 years

© flydime

but if it is given a big enough push (ie enough energy), it reaches the top and immediately drops into the hole. This is essentially how carbon and oxygen atoms interact. Normally they exist near each other but do not mix. However, when a bit of extra power is introduced to the equation, they are suddenly drawn together. Once a carbon and oxygen atom have gained enough energy to 'snap' together, they release a bit of energy in the process. In turn, this allows two other atoms to unite, and two more, and so forth. This eventually leads to a runaway chain reaction and, ultimately, a fire. We'll consider this process in greater depth later.

When these atoms combine to form a new molecule, a certain amount of energy is released or absorbed. The amount created in such a reaction is dependent on how fast the atoms can rearrange themselves and, in the case of fire, this process is extremely rapid. In a slower reaction like rusting, although the principles are similar, the rate of oxidisation is so sluggish that the temperature increases by only about one degree Celsius (1.8 degrees Fahrenheit). If you can accelerate this oxidisation rate though, then you'll suddenly find the amount of energy – and ultimately heat – released also increases; this is combustion. Every substance has a threshold temperature at which the atoms will gain the necessary power to snap together and start a runaway chain reaction, and once this temperature is passed then combustion can begin. If heat cannot dissipate faster than it is created, combustion is all but inevitable.

Understanding what's going on during combustion can be difficult to comprehend, so we will use the relatively simple example of hydrogen ▶

QUICK-FIRE QUESTIONS

Q: How fast is fire?
Although estimates vary largely, most fires (in particular forest fires) are thought to move at about 16-20km/h (10-12mph).

Q: What makes things flammable?
The instability of a substance's atoms and their likelihood to combine with oxygen are what ultimately determine flammability.

Q: How does fire act in zero gravity?
A flame in a zero-gravity environment spreads outwards like a balloon because there is no external force acting on it.

Q: Why does fire 'eat' up oxygen?
Fire is a rapid process of combustion, which itself is caused by oxidisation, where atoms of oxygen combine with other atoms to make new molecules, so fire must consume oxygen.

Q: Why do flames flicker?
In the absence of a draught disturbing the flame, flickering is the fire searching for more oxygen to keep burning.

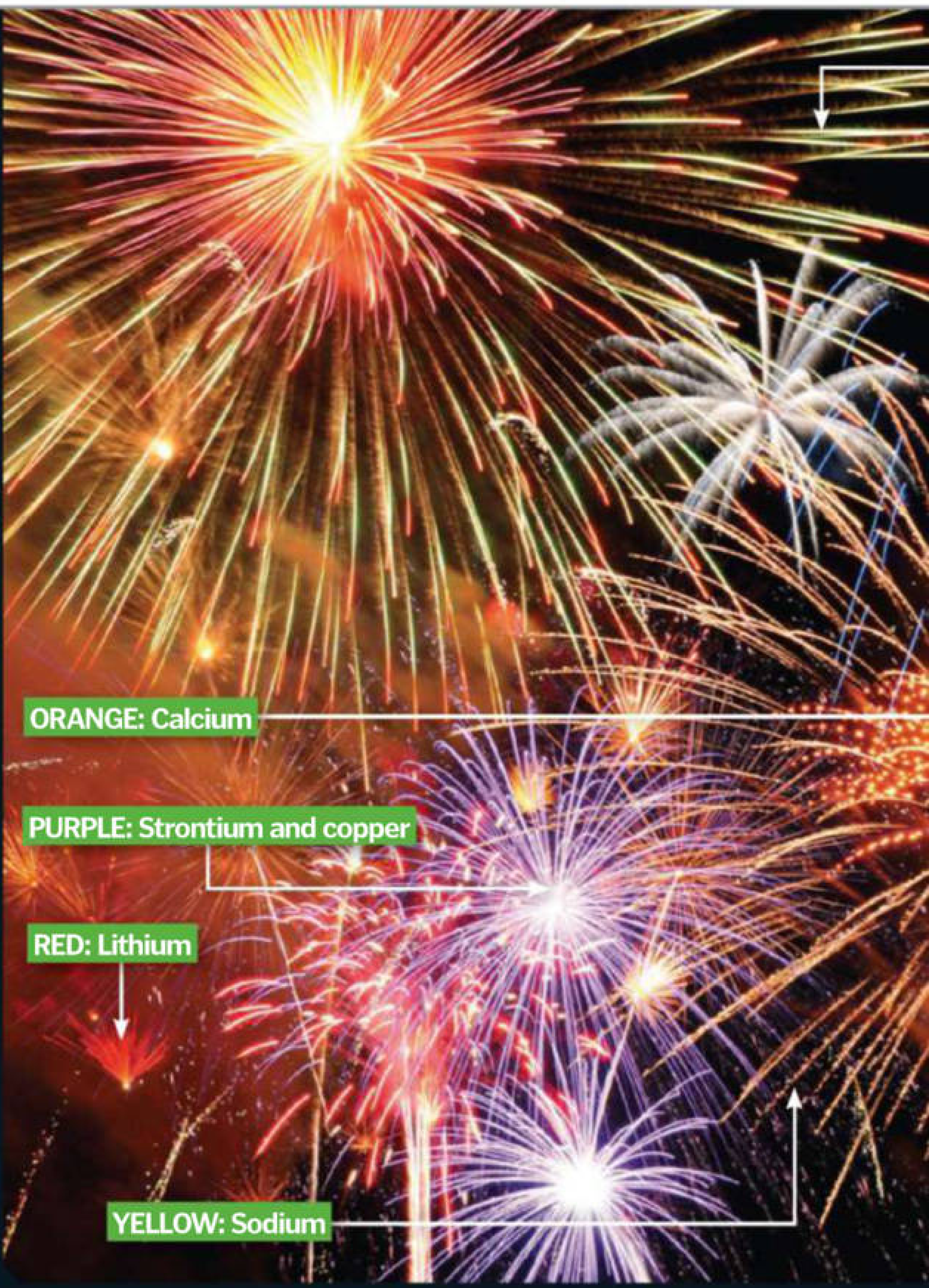
to demonstrate the process. During the combustion of hydrogen, oxygen and hydrogen molecules combine to produce water but, as a by-product of this, heat is also generated. If this heat is greater than the threshold temperature of hydrogen, then another reaction will take place. The rate of combustion in a material is determined by how unstable its atoms are and, in the case of hydrogen and oxygen atoms, they are very unstable. The addition of an external factor such as more atoms or an increase in heat energy will result in a chemical chain reaction taking place as the remaining molecules bond together.

So now we get on to what fire actually is. It might surprise you, but solids and liquids do not actually burn, or rather, they are not responsible for the visible flames we see. Paper, petrol, or indeed any flammable material, doesn't burn itself, but in fact it is the vapours emanating from these solids and liquids that burn. As an example, let's consider how a candle works.

Melted wax travels up the wick and vaporises when it reaches the top, but it doesn't burn itself. The heat from the flame as the wax reaches the top causes it to vaporise and subsequently oxidise, or burn, in turn releasing more heat. This is the same process with paper and wood. The material vaporises, and this heated vapour oxidises, in turn generating further flames and heat. Not all the carbon combines with oxygen to combust though. Some of the carbon forms other molecules, which are responsible for a flame's glow. Soot, composed mostly of carbon, is formed just before it enters the flame. It is these soot molecules growing superhot that cause fire's characteristic reddish glow.

When fuel is pure, the fire appears blue as there are very few impurities. The centre of a flame, as seen in a candle, will often appear blue where there is little other material. Flames that appear red have been overpowered by soot and smoke, which burn bright red under heat, tinting the flame.

The cause of this redness is something known as blackbody radiation. Everything in the universe emits energy, and in some cases this is visible. For example, humans emit infrared energy, so when viewed via night-vision goggles we 'glow'. The measure of the energy an object gives off is known as its blackbody radiation. When something is burning red, it is merely giving off energy corresponding to red on the electromagnetic spectrum. Humans are too cool to burn with this sort of visible light but things like iron, lava and soot in a flame are all able to reach the necessary heat, so they release this visible blackbody radiation. This is why, for the most part, fire appears red when organic substances are feeding it. To learn why some things burn a completely different colour, like purple or gold, see the 'Chemical colours' boxout.



ORANGE: Calcium

PURPLE: Strontium and copper

RED: Lithium

YELLOW: Sodium

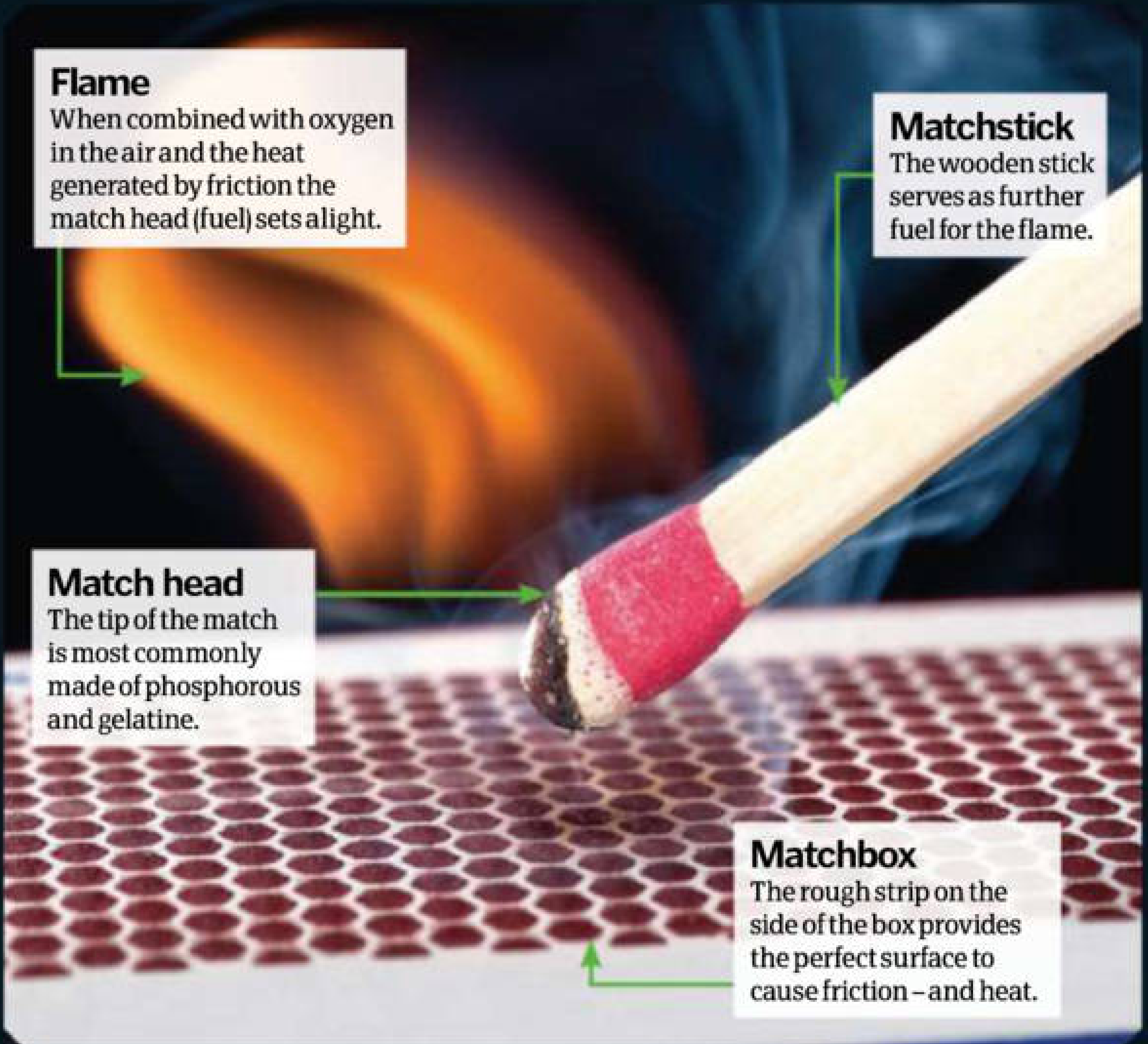
The fire triangle

The essential trio that fire can't do without

For a fire to start – and indeed survive – it requires three things: oxygen, fuel and heat. Let's take the example of striking a match to show how this trio combines to initiate the runaway reaction of combustion.

As you strike the match against the box, the heat produced by friction is higher than the ignition temperature of the tip of the match. The head acts as the fuel, the air contains oxygen and friction causes heat. As the head burns, the fire heats the wooden stick beyond its threshold temperature and causes it to burn too. If the stick were made of, say, metal the match would quickly burn out. In this scenario, once the head had burnt out the fire would no longer have one of its key components – fuel – available, thus it would die.

Fuel, oxygen and heat are needed to both initiate and sustain combustion; this is known as the fire triangle. Each type of fuel has an ignition temperature at which it will rapidly begin uniting with oxygen, ultimately setting alight. With a match, you have two of these three components before it is lit: fuel and oxygen. By rubbing it across a matchbox and creating friction, heat is produced which sparks the chain of reactions in the head of the match and leads to the production of fire. For a match to ignite, it needs a temperature of around 182 degrees Celsius (360 degrees Fahrenheit), which is produced as it travels across a rough surface. Once the match head is ignited, more and more heat is released, resulting in a flame – all in less than a second.

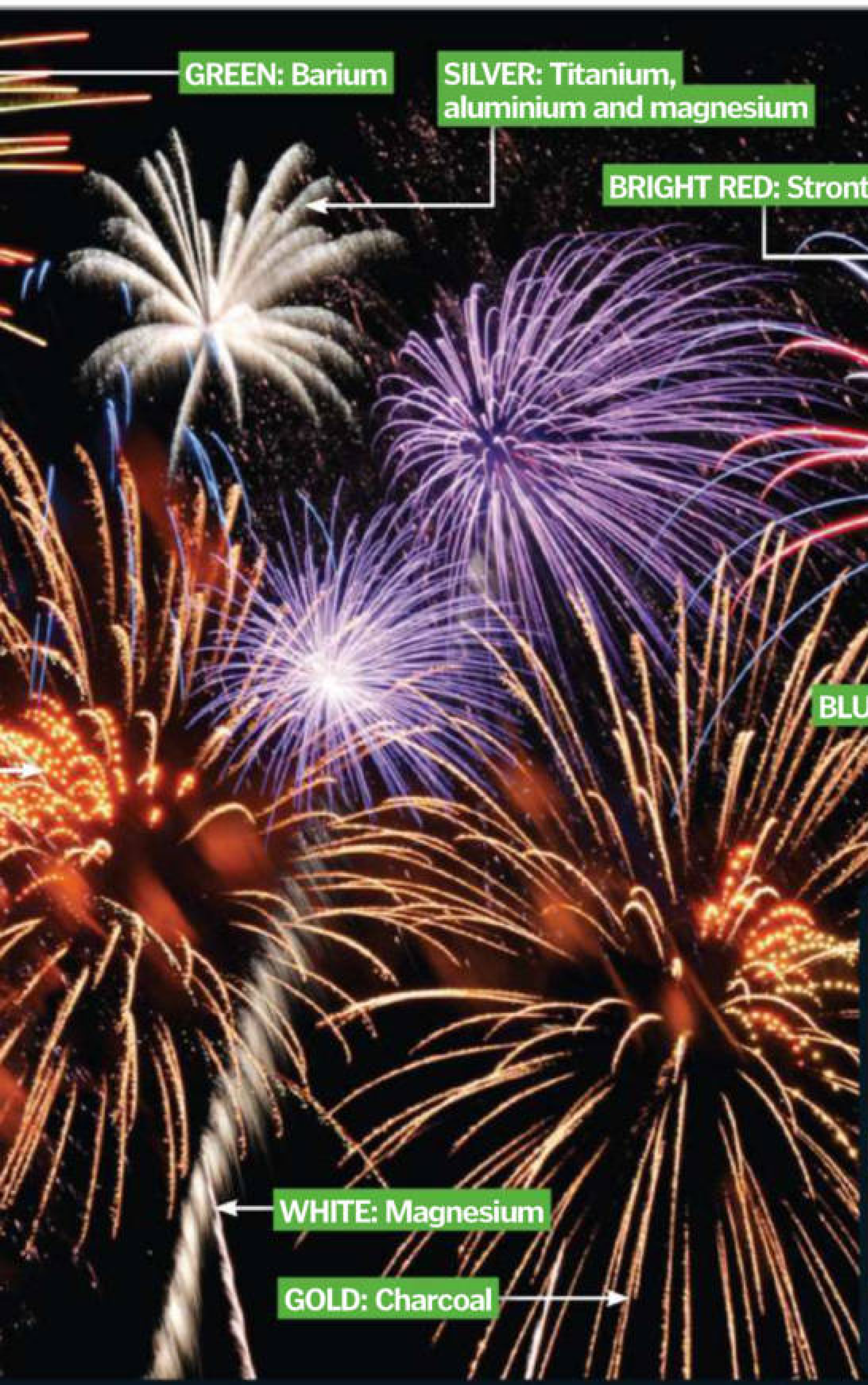


Flame
When combined with oxygen in the air and the heat generated by friction the match head (fuel) sets alight.

Matchstick
The wooden stick serves as further fuel for the flame.

Match head
The tip of the match is most commonly made of phosphorous and gelatine.

Matchbox
The rough strip on the side of the box provides the perfect surface to cause friction – and heat.



CHEMICAL COLOURS

Substances burn with varying colours because they have different threshold temperatures at which they burst into flames. Those that require more heat burn towards the white end of the electromagnetic spectrum, as they require greater energy, and vice versa for red. Fireworks are basically just mini 'stars' of fuel that ignite upon the addition of oxygen and heat as per the fire triangle (see the opposite page).

Light produced from heat is known as incandescence. It is the heat that causes a substance to glow, and as it does so the matter will first emit infrared light (as humans do naturally), followed by red, orange, yellow and white light as it gets hotter. By controlling the level of heat, a firework's glow can be manipulated to produce the desired colour/effect.

The Space Shuttle's engines combusted hydrogen in order to provide propulsion

© NASA

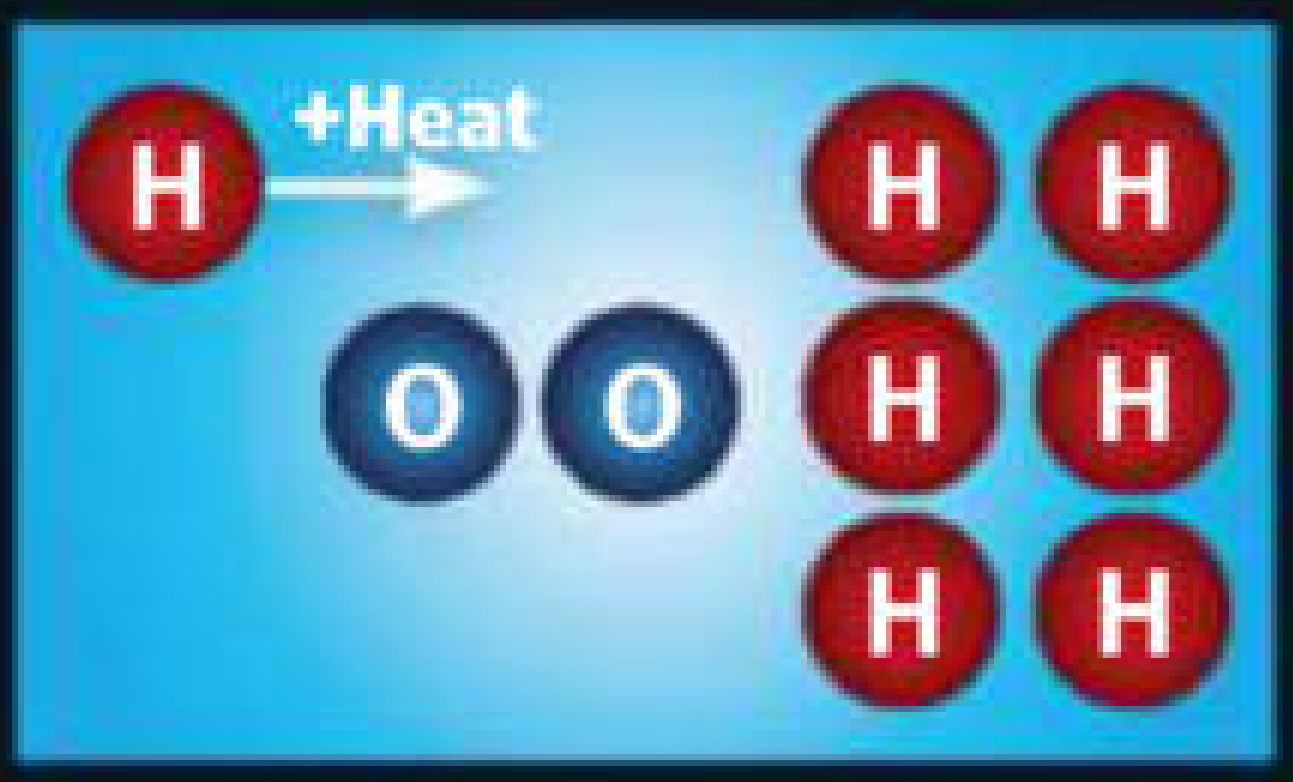
Combustion

How this process can spark an inferno

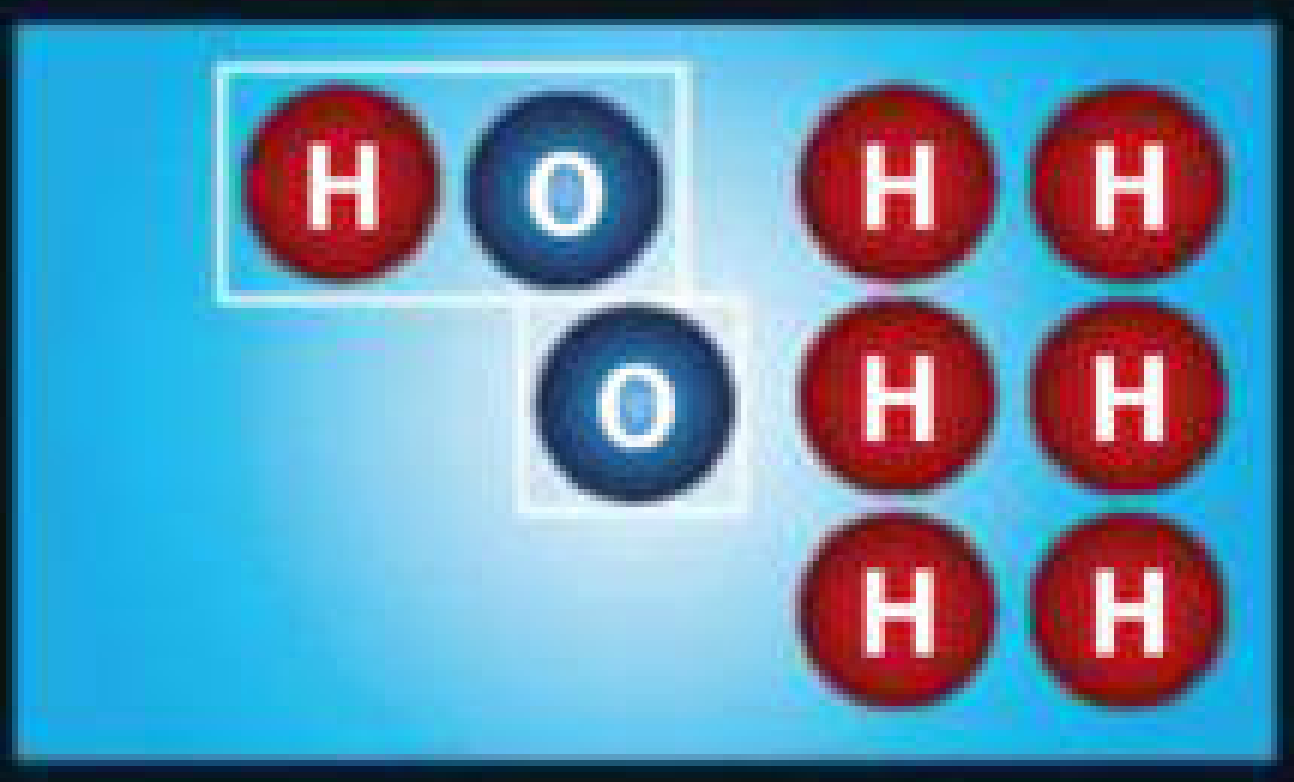
Combustion is the process through which atoms can gain enough energy to surpass their temperature threshold and bond with others to form entirely new molecules.

Energy is released in this process in the form of heat, which in turn causes other atoms to bond in similar ways. Essentially, this leads to a runaway chain reaction where many atoms in a material suddenly find themselves with enough energy to exceed their temperature threshold.

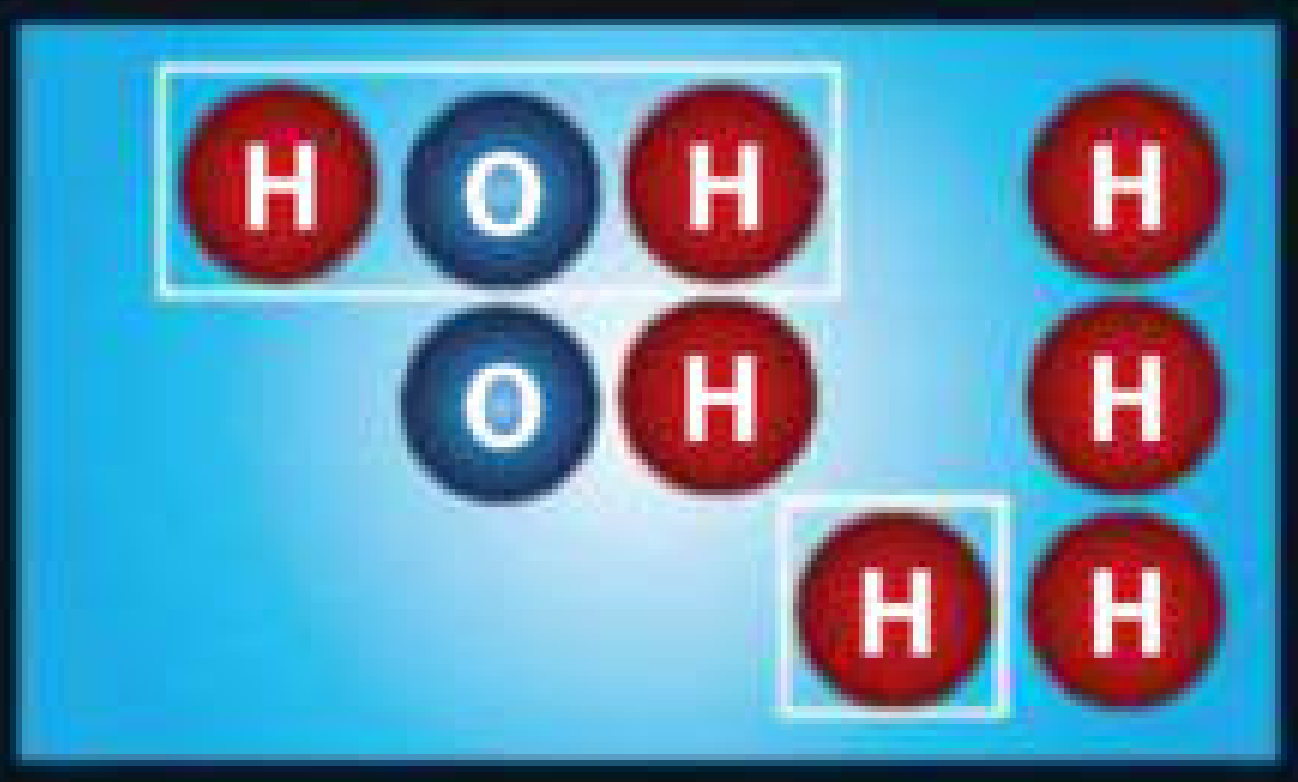
The general rule is, if heat is created faster than it can dissipate, then combustion will occur. Ultimately, a high enough level of sustained combustion will lead to fire.



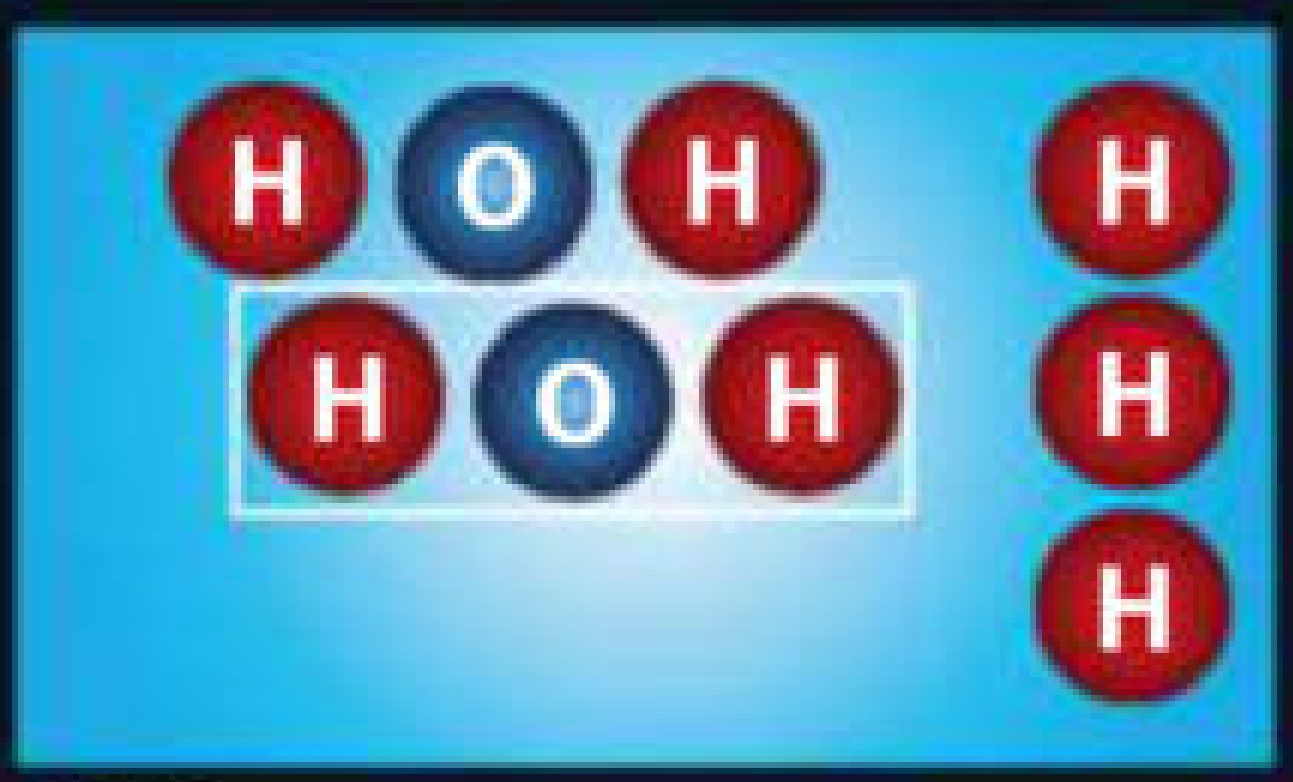
1. Stable
The introduction of energy, such as heat, to a stable mix of oxygen and hydrogen gas can trigger a sudden chain reaction.



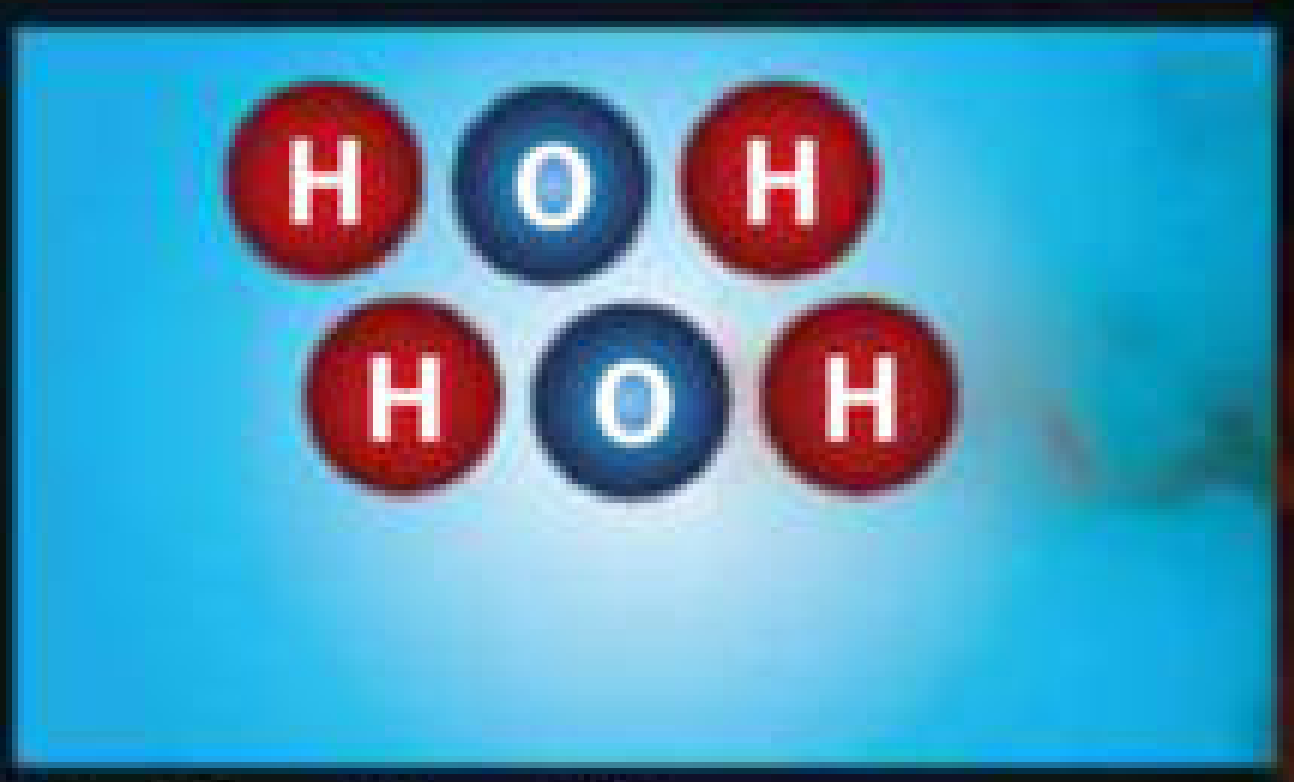
2. Reaction
With enough energy, a hydrogen atom (H) reacts with a molecule of oxygen (O_2), forming one hydroxyl radical (OH) and an oxygen atom (O).



3. Water
The OH molecule reacts with a molecule of hydrogen (H_2), producing a water molecule (H_2O) and a hydrogen atom.



4. Runaway
The atom of oxygen freed earlier reacts with another H_2 to produce a new H_2O molecule and H atom. Steps 2 and 3 then repeat.



5. Combustion
Three freed H atoms react with three O_2s, producing nine H atoms, which liberate 27 more and so on. This chain reaction is combustion.

QUICK-FIRE QUESTIONS

Q: Why do flames appear pointy?
The Earth's gravitational pull is responsible for making hot air rise. It is this convection which shapes flames into their familiar pointed form.

Q: What is backdraught?
When a fire has used up all its available oxygen, the surrounding environment can remain hot and airtight until new oxygen is introduced, when a power re-ignition backdraught explosion can occur. This dangerous phenomenon is often seen by firefighters.

Q: What is smoke?
Smoke results from volatile organic compounds evaporating from a fire, creating a visible plume of rising gaseous material.

Q: Why do things burn at different temperatures?
It's due to the strength of the bonds and the sizes of atoms and molecules in various materials. As you'd expect, stronger, more stable atoms need more energy to combust.

Q: Is spontaneous combustion possible?
This as-yet-unproven process involves the sudden combustion of an entire object when a heat source is introduced. Its existence is cause for 'hot' debate among scientists.

How do noble gases work?

What makes this select bunch of chemical elements so 'noble'?

There are six naturally occurring noble gases found around our world and beyond. These are helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn). Together they form Group 18 of the periodic table and are characterised by their lack of colour, smell, taste and flammability in their natural state.

Despite being historically referred to as rare and inert, noble gases – which were designated 'noble' due to their apparent reluctance to undergo a chemical reaction – are nothing of the sort. In fact, all of these gases are found in Earth's atmosphere and each is fully capable of being chemically active and producing compounds.

The majority of the noble gases – ie argon, krypton, neon and xenon – are formed via liquefaction and fractional distillation techniques, however helium is attained by separating it from natural gas and radon by isolating it from the radioactive decay of radium compounds.

As noble gases show extremely low chemical reactivity, while they are not inert, only a few hundred noble gas compounds have been formed to date, with xenon varieties making up the bulk of them. In theory, though, radon is more reactive than xenon, so it should form chemical bonds more readily. However, its high radioactivity and short half-life are the key factors which prevent this.

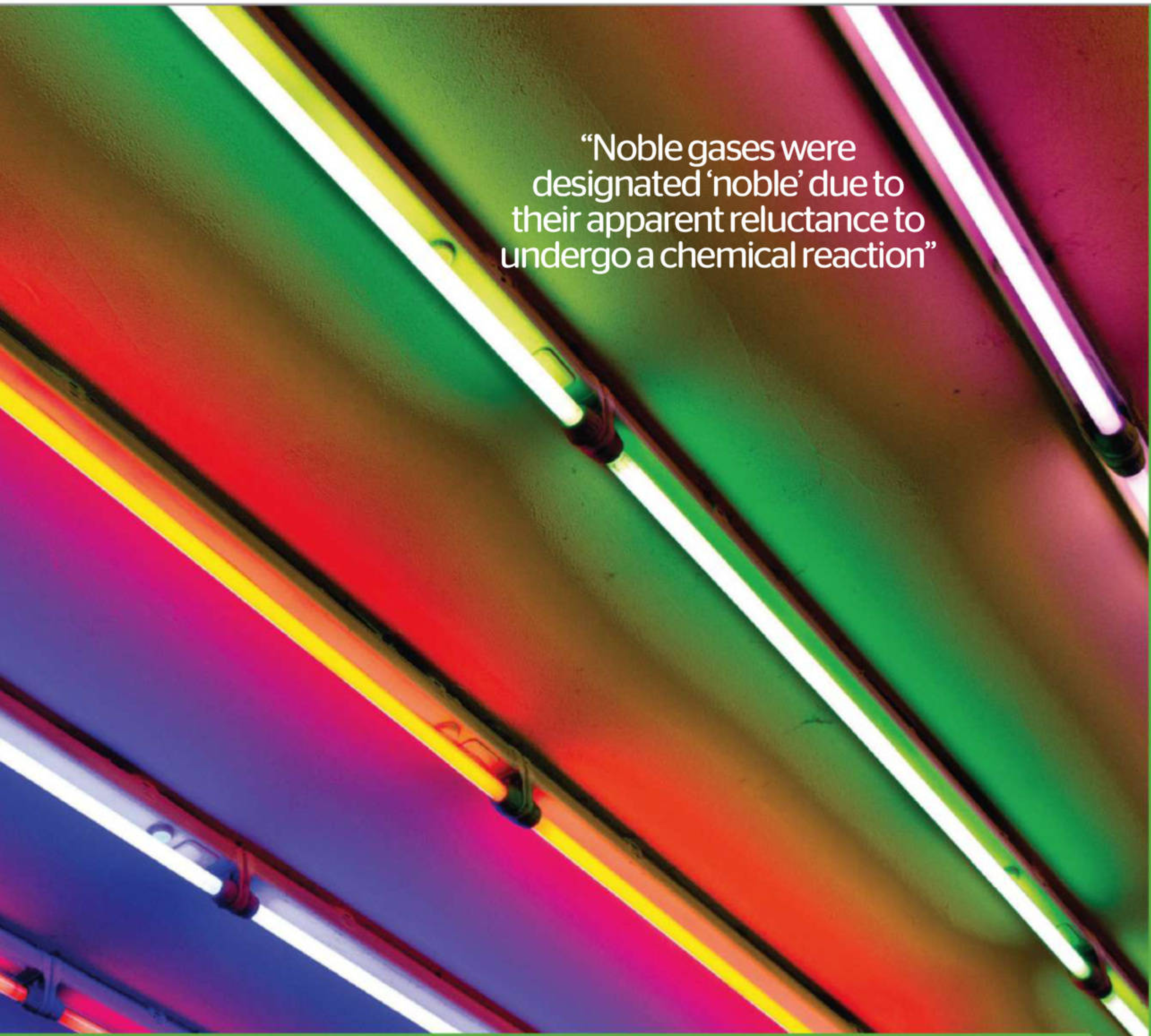
There are many applications for noble gases (see the boxout below for some notable examples). The most obvious and visible of these are illuminated signs, light bulbs and lamps, with xenon, argon and neon commonly used due to their lack of chemical reactivity. Using these gases helps to preserve filaments in light bulbs and grants distinctive colours when used in gas-discharge lamps – as demonstrated by the main image on this page. ✲

Where are noble gases used?

Arc lamps
A specialised type of gas-discharge lamp, arc lights pass electricity through a bulb full of ionised gas, such as xenon or argon. They're used in IMAX cinemas among other places.

Blimps
Today, most blimps are filled with helium due to its lightness and incombustibility. Hydrogen was used originally but was phased out due to its high flammability.

MRI scanners
One of the most advanced pieces of medical equipment, magnetic resonance imaging scanners use liquid helium to cool the superconducting magnets inside.



> "Noble gases were designated 'noble' due to their apparent reluctance to undergo a chemical reaction"

Illuminated signs
Many illuminated signs and billboards utilise noble gases due to their ability to generate vibrant colours when ionised – neon lights being a prime example.

Refrigerants
Due to their incredibly low boiling points – for instance, argon boils at -186 degrees Celsius (-302.8 degrees Fahrenheit) – the Group 18 gases are often used in cryogenics.

Radiotherapy
Despite the noble gas radon being highly radioactive and able to cause cancer, it can also be used as part of radiotherapy treatments to control or kill malignant cells.

© Atlant; Getty; Thinkstock

Acids and bases

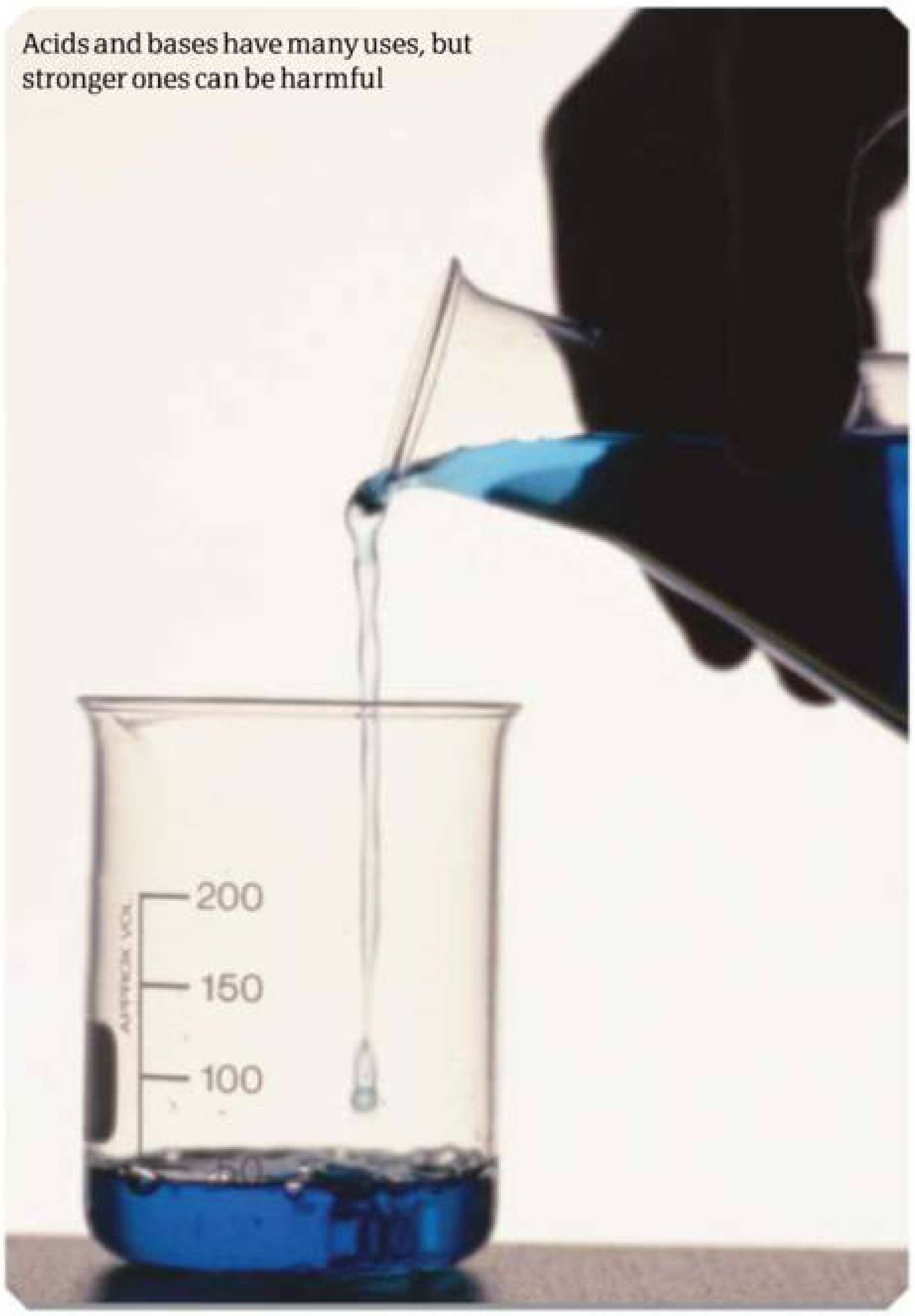
See the differences between acids and bases, and find out why they act the way they do

It is widely known that lemons taste sour due to their acid content, soil needs the optimum pH level for plants to grow properly and acid rain can wipe out entire ecosystems. But what really makes one thing acidic and the other one basic (alkaline)? Why can they be so corrosive? And why does litmus paper turn different colours when dipped in acid or a base?

Acids and bases can be defined in terms of their concentration of hydrogen ions. Normally an atom of hydrogen consists of one proton and one electron giving it a balanced electrical charge – protons being positively charged and electrons being negatively charged. Take away the electron and you are left with an ion of hydrogen, or a single proton, or 'H+', as it is often written. The thing about ions is they are very reactive, as they no longer have a balanced charge. They are constantly seeking ions of the opposite charge – an atom or molecule with an unequal number of electrons than protons, with which to react.

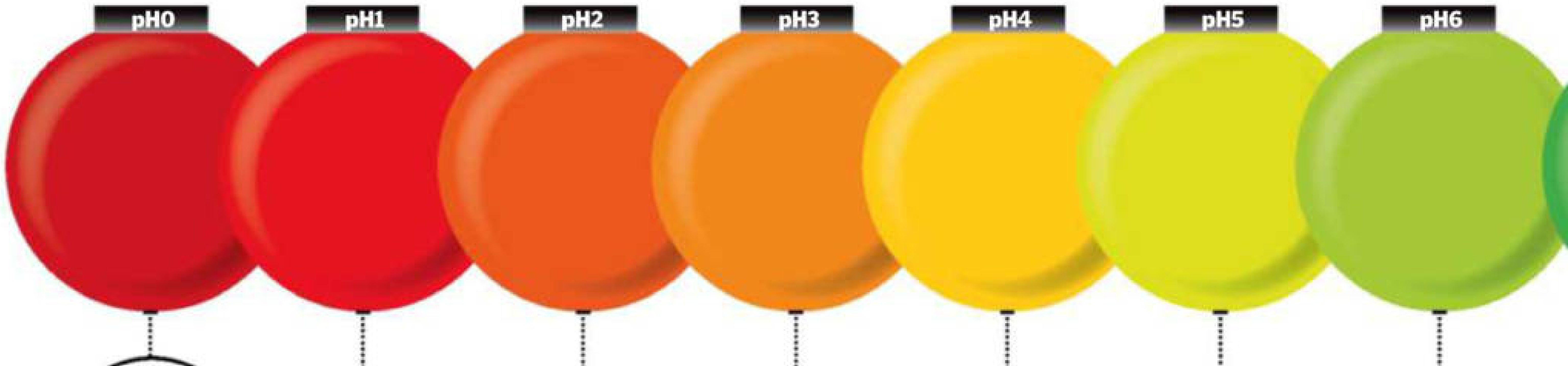
A strong acid has a high concentration of H+ ions and is defined by its ability to 'donate' hydrogen ions to a solution, whereas a base, also know as an alkali, has a much lower concentration of H+ ions and is defined by its ability to 'accept' hydrogen ions in a solution. Therefore, acids mixed with bases become less acidic and bases mixed with acids become less basic, or less alkaline.

Certain concentrated bases, like some concentrated acids, can attack living tissue and cause severe burns due to the ions reacting with the skin. However, the process of bases reacting with the skin, and other materials, is different to that of acids. That's why we call some concentrated acids 'corrosive', whereas reactive concentrated bases are 'caustic'.


Acids and bases have many uses, but stronger ones can be harmful

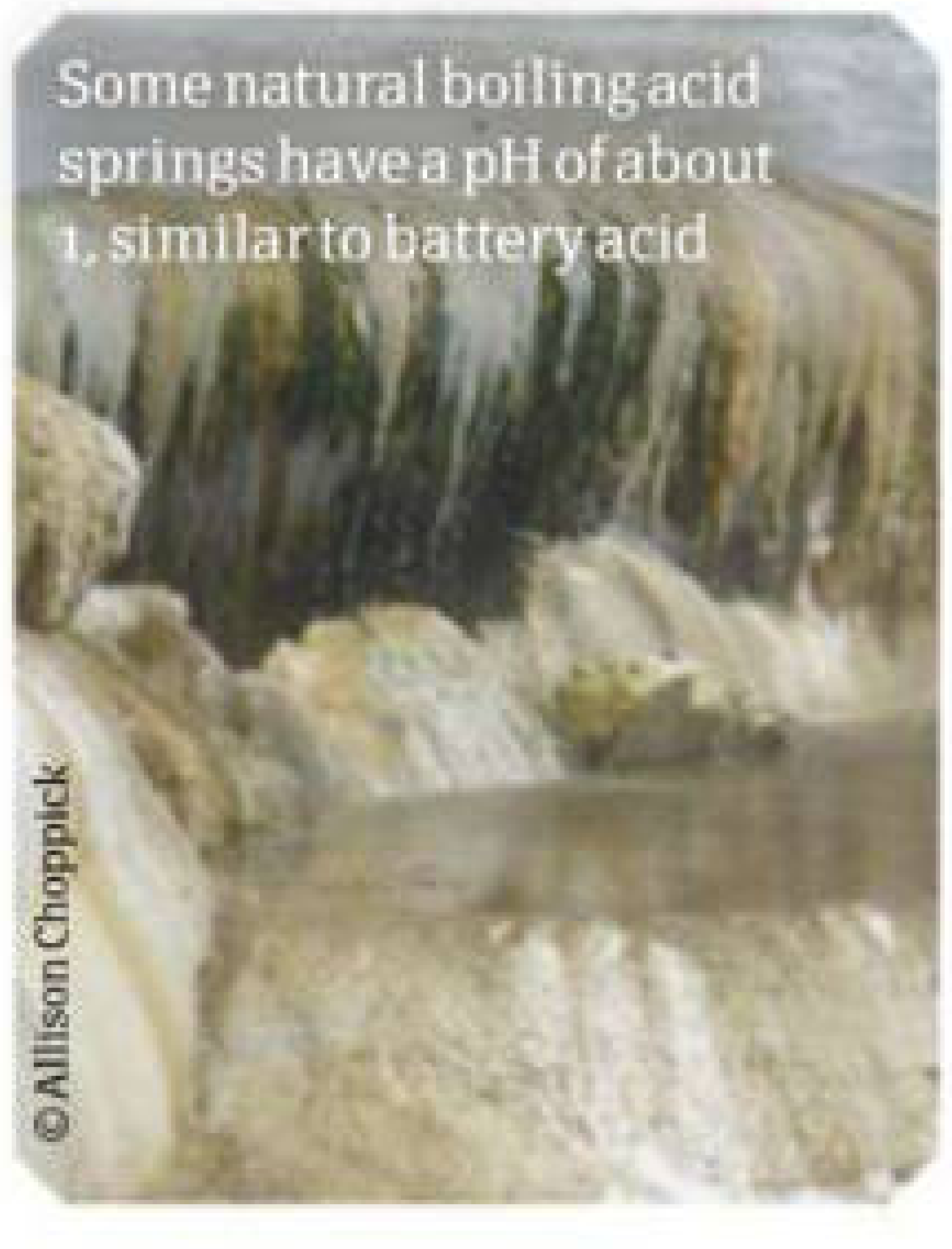
The power of hydrogen

The letters pH stand for 'power of hydrogen', as the scale refers to the concentration of hydrogen (H+) ions in the solution. It measures the acidity or basicity of a solution, with pH values ranging from 0-14, 0 being really acidic and 14 being really basic. A substance in the middle of the scale with a pH of 7 is classed as neutral, as it contains equal numbers of oppositely charged ions.



Acid

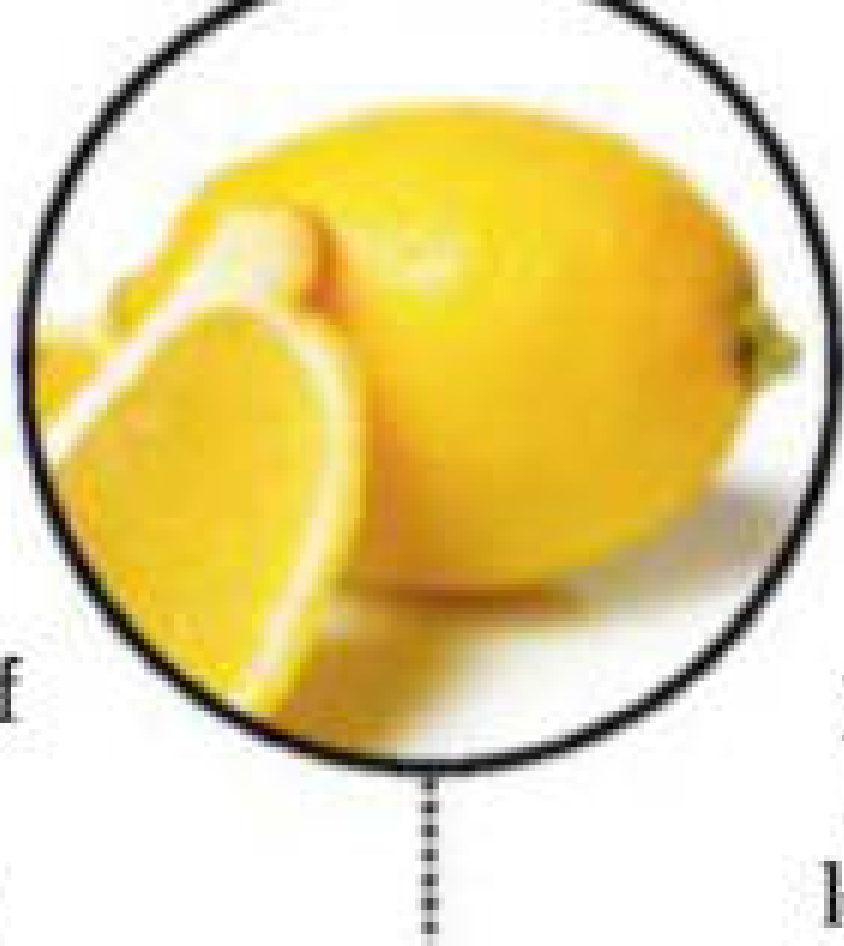
A compound which 'donates' hydrogen ions when placed in an aqueous solution. The higher the concentration of hydrogen ions released, the stronger the acid.


Some natural boiling acid springs have a pH of about 1, similar to battery acid

© Allison Choppick

Hydrofluoric acid
A highly corrosive substance which as a gas is a severe poison and acts a catalyst in oil refining.

Suphuric acid
Used in the production of fertilisers, this strong acid is a chemical found in acid rain.



Lemon juice
Lemon juice is about 5% citric acid – a weak organic acid that gives lemons their sour taste.

Cola
Cola contains phosphoric acid, which has been linked to the lowering of bone density in various studies.

Beer
Various acids are formed during the fermentation process in beer production. The addition of CO_2 also causes the pH to lower slightly.

Black coffee
Levels of acids found in coffee can be affected by the altitude at which the coffee was grown and the minerals present in the soil.

Cow's milk
Milk goes sour over time due to the bacteria producing lactic acid as part of a fermentation process.

Find pH with litmus tests

We can test the acidity or alkalinity of a substance using litmus paper. Litmus paper is that which has been treated with a mixture of 10-15 natural dyes obtained from lichens. The dyes work as indicators, whereby upon exposure to acids (a pH less than 7) the paper turns red and upon exposure to bases (a pH more than 7) the paper turns blue. When the pH is neutral (pH equal to 7), the dyes cause the paper to turn purple.

Red cabbage juice can also be used to distinguish between acids and bases, as it contains a natural pH indicator called 'flavin'. Upon exposure to acid, flavin turns a red colour, neutral solutions appear a purple colour and basic solutions result in a greenish-yellow colour.

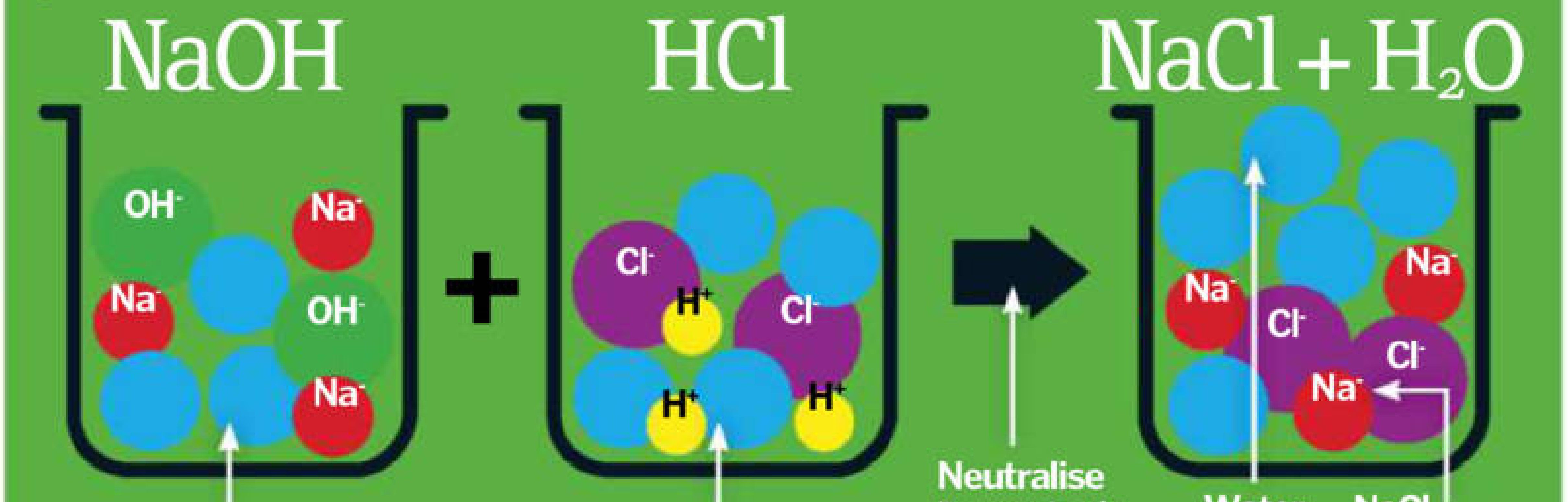
Neutralisation

Wasp stings are alkaline, so an acid-like vinegar will neutralise them

A neutralisation reaction is the combination of an acid and base that results in a salt and, usually, water. In strong bases and acids, neutralisation is the result of the exchange of hydrogen and hydroxide ions, H+ and H- respectively, which produces water. With weak acids and bases, neutralisation is simply the transfer of protons from an acid to a base. The production of water, with a neutral pH of 7, indicates the neutralisation of the acid and base, while the resultant salt will often have a pH that is also neutral.

Neutralisation has a variety of practical uses. For example, as most plants grow best at neutral pH7, acidic or alkaline soil can be treated with chemicals to change its pH. In the case of acidic soil this is often calcium carbonate (chalk) or calcium oxide (quicklime). Another example is the human stomach, which contains hydrochloric acid. However, too much can lead to indigestion, so the acid can be neutralised with a base such as an indigestion tablet.

How do an acid and base react to produce salt, water and heat?



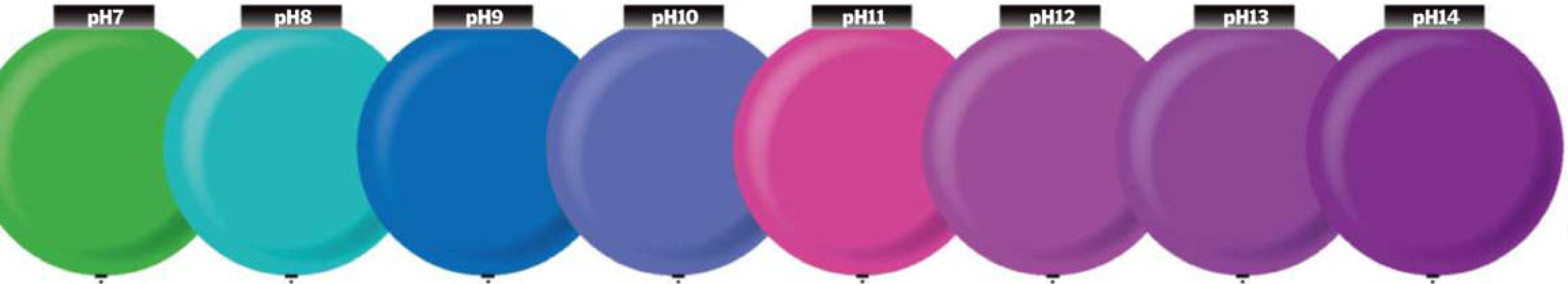
Sodium hydroxide This strong alkali (a base soluble in water) has a pH of 13 or 14.

Hydrochloric acid With a pH of 1 or 2, the H+ ions of this strong acid are removed by the alkali.

Neutralise By removing the H+ ions, the alkali neutralises the acid and turns the ions into water.

Water Neutral water of pH7 is produced.

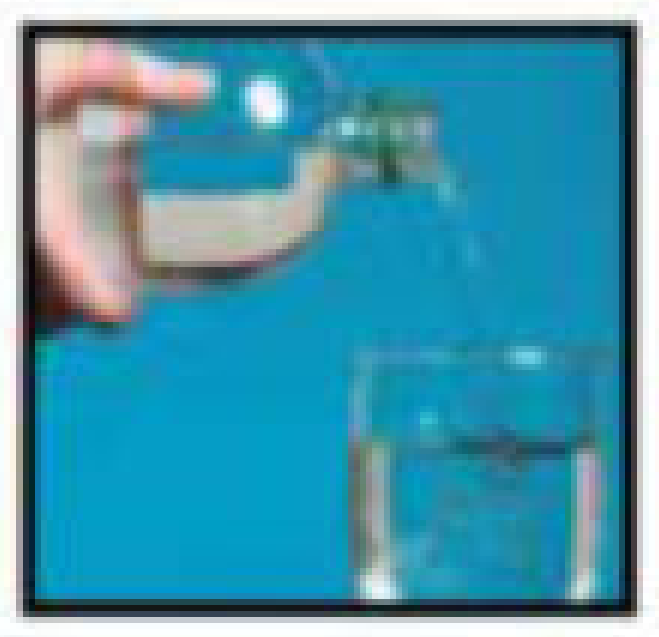
NaCl Neutral sodium chloride, or table salt, is also produced.



Base

A compound which 'accepts' hydrogen ions in an aqueous solution. Contains ions of the opposite charge. For example, hydroxide (OH-) which is naturally found in water and is negatively charged.

Distilled water Pure water is neutral as it contains the same amount of positive ions as negative ions, though most water isn't pure in this sense.



Baking soda A slightly salty substance used as a base in foods to regulate the pH if something is too acidic.

Toothpaste Acidic toothpaste can put enamel at risk of decay, so a weak base such as sodium hydroxide is added in order to regulate the pH.

Milk of magnesia A weak base of magnesium hydroxide in water, used to ease stomach aches caused by too much acid.

Ammonia solution When placed in water, ammonia removes protons from a small fraction of the water to form ammonium and hydroxide. It is used in many cleaning products for its basic properties.

Bleach Can contain sodium hypochlorite at different strengths, making it a strong caustic base.

Caustic oven cleaner Heavy-duty oven cleaners can be really caustic and corrosive, helping to break down fat and grease.

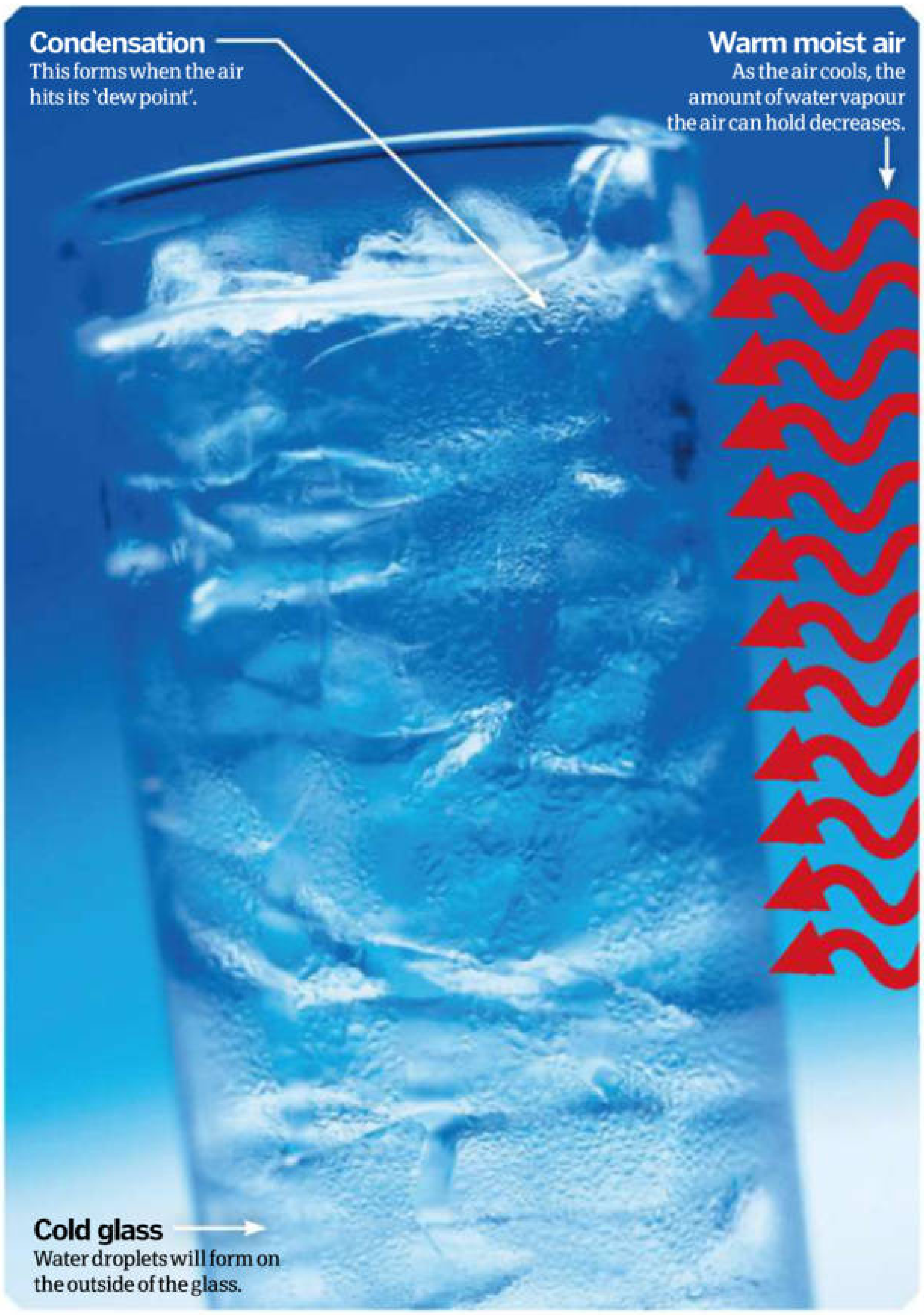
Caustic soda Chemically known as sodium hydroxide, in its purest form it is a white solid and can cause severe burns due to its high alkalinity.

What is condensation?

Anyone who's had a cold drink on a hot day has seen condensation in action

Air contains water vapour in various quantities depending on where it is in the atmosphere. The amount of water vapour air can hold is dependent on its temperature – with the amount decreasing as the air itself begins to cool. The lower the air temperature, the less water the air is capable of holding. This increases the overall humidity of the air until – if the temperature drops low enough – the air hits what is known as the 'dew point'. This is the point at which the excess water vapour literally condenses out of the air and forms water.

What's genuinely fascinating is how this process differs depending on the location of the air. Warm air that's cooled to the dew point due to expanding and rising forms clouds. The cooling of a large amount of air near the ground, however, will cause mist or fog to form. Air in contact with the ground will become dew if its dew point is above 0°C, or it will become frost if it's below.



Condensation
This forms when the air hits its 'dew point'.

Warm moist air
As the air cools, the amount of water vapour the air can hold decreases.

Cold glass
Water droplets will form on the outside of the glass.

Boiling water

Steam
As the vapour cools and condenses, it produces visible steam.

Vapour pressure
Evaporation occurs when the vapour pressure reaches that of the surrounding air.

Boil
When water boils at 100°C (212°F), vapour pressure increases.

© Science Photo Library

Evaporation and steam

How do these processes work, and is there a difference between them?

The change of state from a solid or a liquid to a vapour is known as 'evaporation'. This change of state occurs from the amount of energy the molecules have. Apart from at absolute zero (-273.15 °C), when molecules are said to have zero energy, molecules are in constant motion and, as temperature increases, they gain more and more energy.

This in turn increases their movement and, the faster they move, the more likely they are to collide with one another. When these collisions occur, a molecule can gain enough energy – and subsequently heat – to rise up into the atmosphere.

However, there is a difference between evaporation of vapour and steam. While vapour can be said to be any substance in a gaseous state at the same temperature as its environment, steam is specifically vapour from water that is hotter than the surrounding environment, commonly seen when boiling. There is no difference in chemical composition of the two. The steam we actually observe is the vapour cooling and condensing as it leaves the hot water and enters the cooler surrounding air.

States of matter explained

Every object on Earth fits into one or more of these phases, but how do they differ at an atomic level?

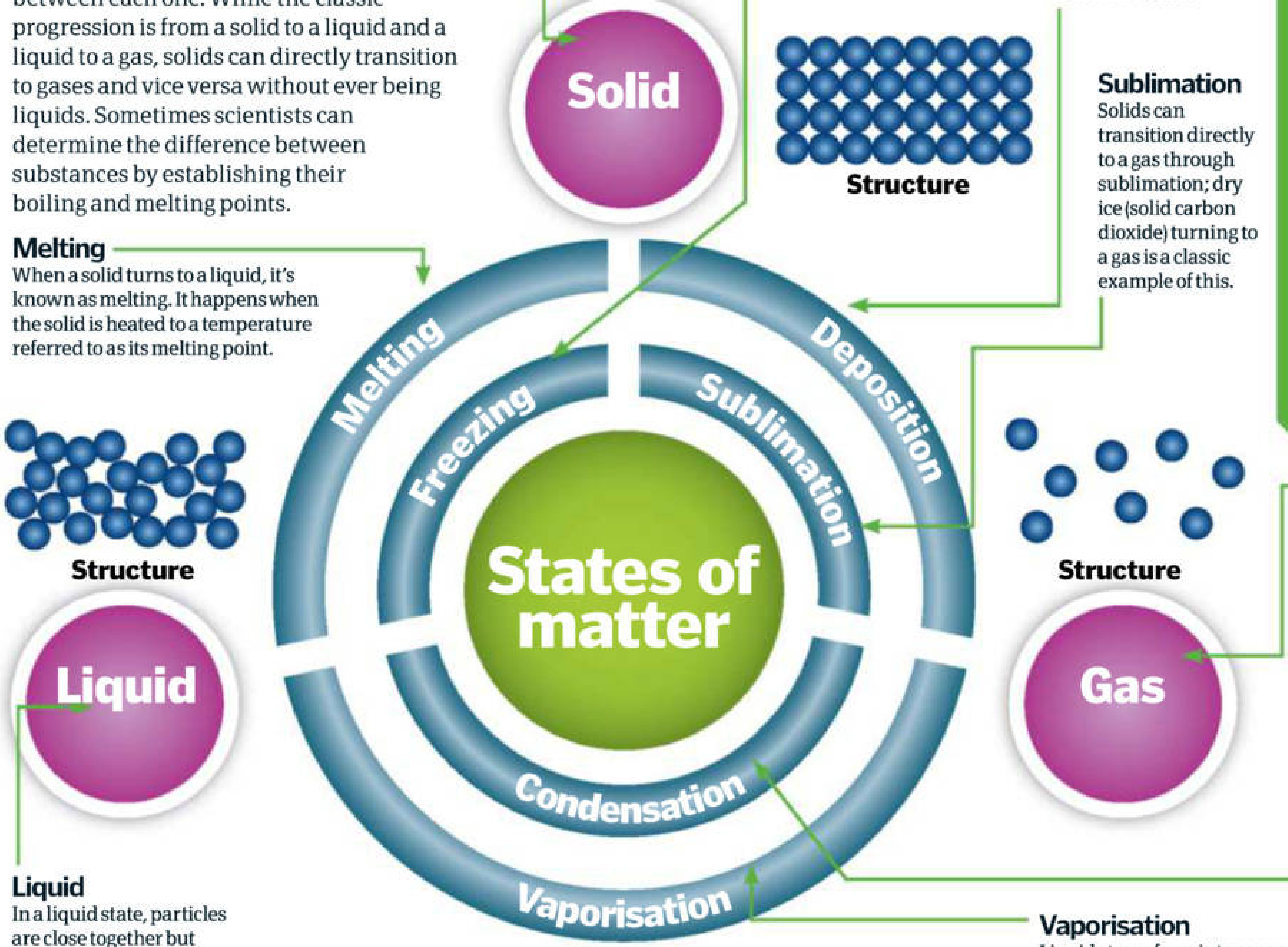
Every single object is either a solid, a liquid, a gas or some combination of the three. Some things can move between states, and some can't. Your bookcase is going to remain a solid, for example, but water changes depending on the temperature. A block of water ice though, still has the same chemical makeup as water in its gaseous form (steam), so what's the difference? A solid object stays the same shape and takes up the same amount of space, or volume. Liquids take up the same amount of space but adapt to the shape of a container and gases expand. To really see the difference, you'd need to check things out at a microscopic level.

If you looked at water in its various phases under a powerful microscope, you would see that the particles in each behave very differently. When it's a vapour (steam), the water particles vibrate and are moving very quickly. They're loose and slide freely around with no particular arrangement. In comparison, liquid water particles also vibrate and can move around easily, but they're more tightly packed and don't move anywhere near as fast as their gaseous counterparts. Finally, a block of solid ice doesn't move (that is, the particles still vibrate but not enough to go anywhere). This is because its particles are tightly and rigidly packed together in an ordered pattern.

Glacial ice covers roughly ten per cent of land on Earth and forms seven per cent of the oceans

Phase transitions

No matter what the substance, the names of the state changes, or phase transitions, remain the same. When and how it changes depend on the temperature and pressure, and there can be sub-states (or mesophases) between each one. While the classic progression is from a solid to a liquid and a liquid to a gas, solids can directly transition to gases and vice versa without ever being liquids. Sometimes scientists can determine the difference between substances by establishing their boiling and melting points.



Solid
Particles in solids are densely packed and barely move at all.

Freezing
Liquids transition to solids when they reach a specific temperature for the substance known as its freezing point.

Deposition
Also called desublimation, this is when a gas moves directly to a solid without passing through the liquid phase, such as water vapour turning to snow in clouds.

Sublimation
Solids can transition directly to a gas through sublimation; dry ice (solid carbon dioxide) turning to a gas is a classic example of this.

Melting
When a solid turns to a liquid, it's known as melting. It happens when the solid is heated to a temperature referred to as its melting point.

Gas
Gases have particles that move quickly and are spaced widely apart.

Condensation
Condensation is the mesophase between a gas and a liquid.

Liquid
In a liquid state, particles are close together but can still move freely.

Vaporisation
Liquids transform into gases through vaporisation.

Plasma: the fourth state

The three states of matter – liquid, gas and solid – are considered the 'classical states', but there are other states of matter too. In fact, throughout most of the universe matter exists as plasma, a state that can occur when certain gases are heated, causing some of the particles in the gas to become ionised. Ionisation means that the number of electrons in an atom is no longer equal to the number of protons and so the particles are either positively or negatively charged. So plasma as a whole is neutral, as it's made up of roughly equal numbers of positive and negative ions.

All stars are made predominantly of plasma, and the spaces between the stars and galaxies are full of it. It's also present on Earth in phenomena like lightning and the polar auroras. It can be artificially created too and is used in things like TVs, lasers and neon signs.

How do superconductors work so efficiently?

Superconductors may seem like perfectly ordinary materials, but turn down the thermostat and their superpowers are revealed…

Superconductors are metals (such as lead) or oxides which conduct electricity with no resistance. There's just one catch – to display their superpowers, they need to be kept at a frosty -260 or so degrees Celsius (-436 degrees Fahrenheit).

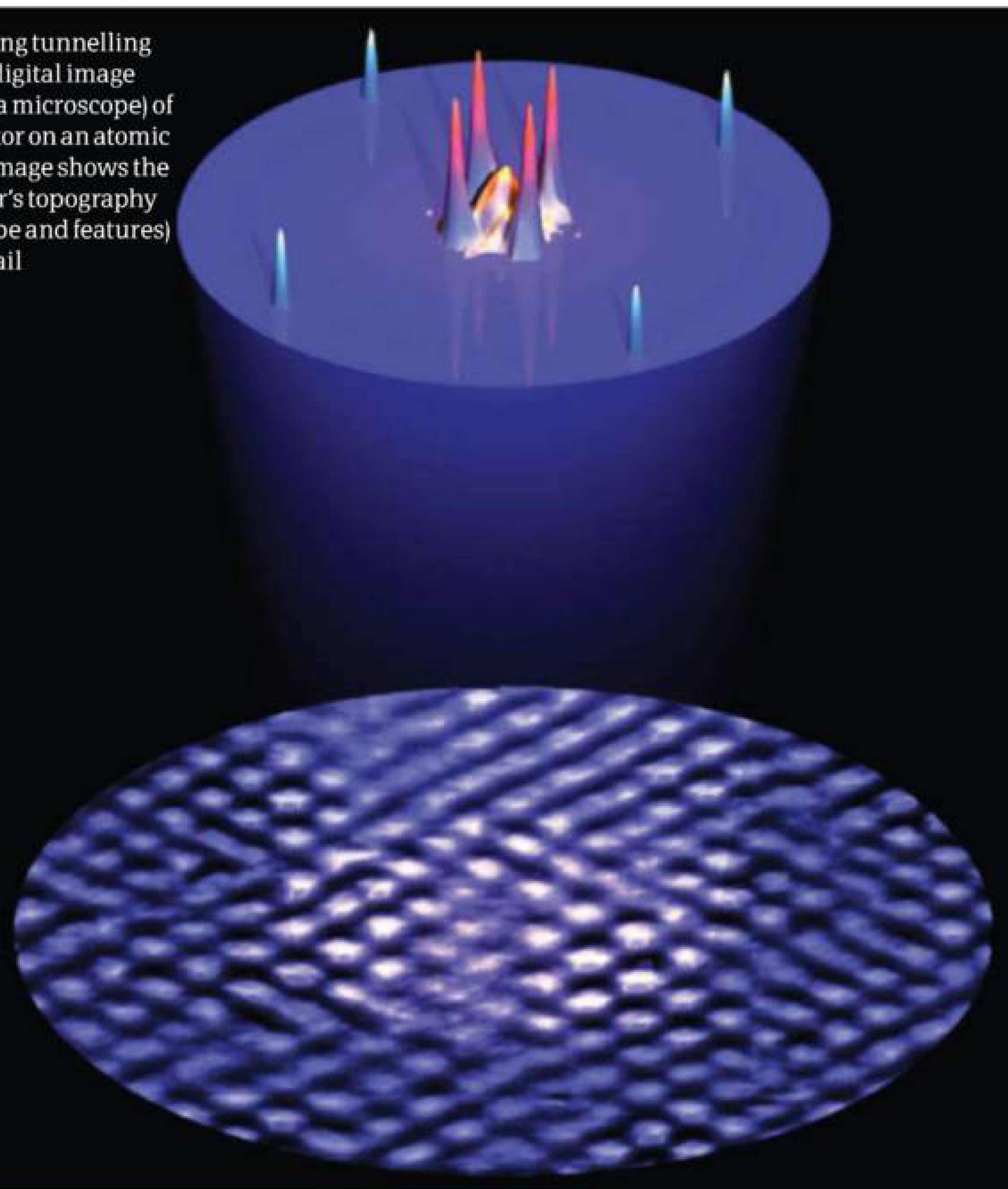
Peer inside a chunk of lead and you'll see row upon row of neatly packed ions, bathed in a swarm of electrons. These loose electrons are what conduct electricity – set them into motion and you have an electrical current. At room temperature, the lead ions vibrate away frantically. From an electron's perspective, it's like trying to negotiate a crowded school corridor without dropping your books. Constant collisions between electrons and ions convert electrical energy into heat; this is resistance.

Turn the temperature down a few hundred notches though and the ion vibrations subside, creating a stable lattice. Now, as electrons flow through, a new effect comes into play: distortions in the lattice force them into pairs.

These unlikely unions trigger a weird quantum physics quirk: electron pairs throughout the material coalesce into a perfectly synchronised cloud, moving a bit like a school of fish. This means the swarm of electrons can move through the lattice with no collisions, and so no resistance.

Thanks to this astounding property, a huge current can be run through a superconductor without it overheating. This means that they can create incomparably powerful electromagnets. These are currently used in MRI scanners, supercomputers, particle accelerators (like the LHC) and levitating maglev trains.

> "Loose electrons conduct electricity"



This is a scanning tunnelling micrograph (a digital image taken through a microscope) of a superconductor on an atomic scale. The top image shows the superconductor's topography (its surface shape and features) in close-up detail

Top metal superconductors

Here are the best metal (Type 1) superconductors with their critical transition temperatures – the point at which it is necessary to cool them before they will superconduct

Lead	7.196 K
Lanthanum	4.88 K
Tantalum	4.47 K
Mercury	4.15 K
Tin	3.72 K

Superconductor evolution

Here we take a journey through the last century in order to see just how far superconductors have come…

1911

Absolute zero

Dutch physicist Kamerlingh Onnes (right) and a student create temperatures just above absolute zero and discover that mercury is a good superconductor.

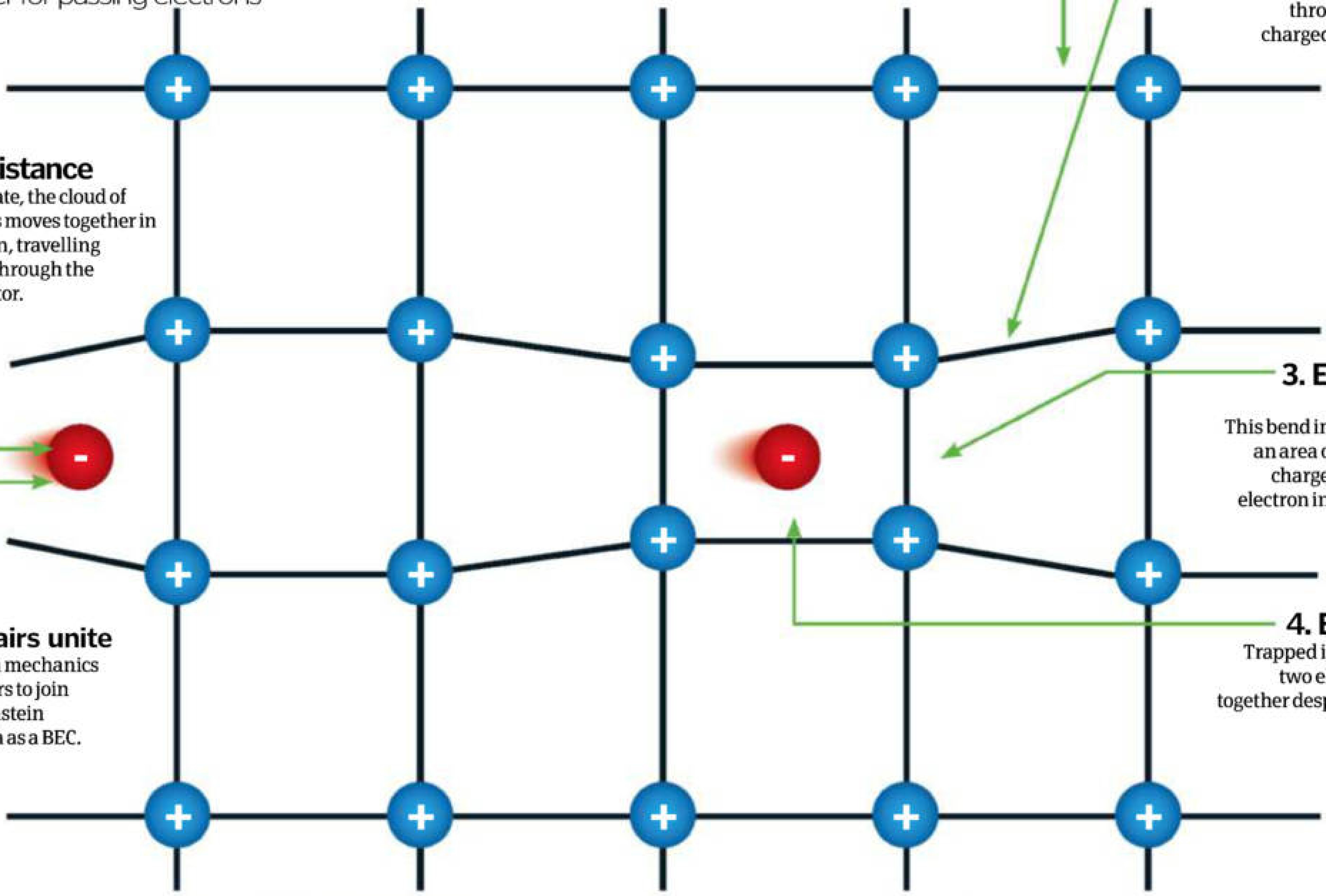
1933

Levitation

Meissner and Ochsenfeld discover the Meissner effect: the uncanny ability of superconductors to repel magnetic fields and cause magnets to levitate.

Superconductors in action

Find out how superconductors make life a whole lot easier for passing electrons



1. Frozen lattice
At temperatures approaching absolute zero, the superconductor's ions barely vibrate, forming a stable lattice.

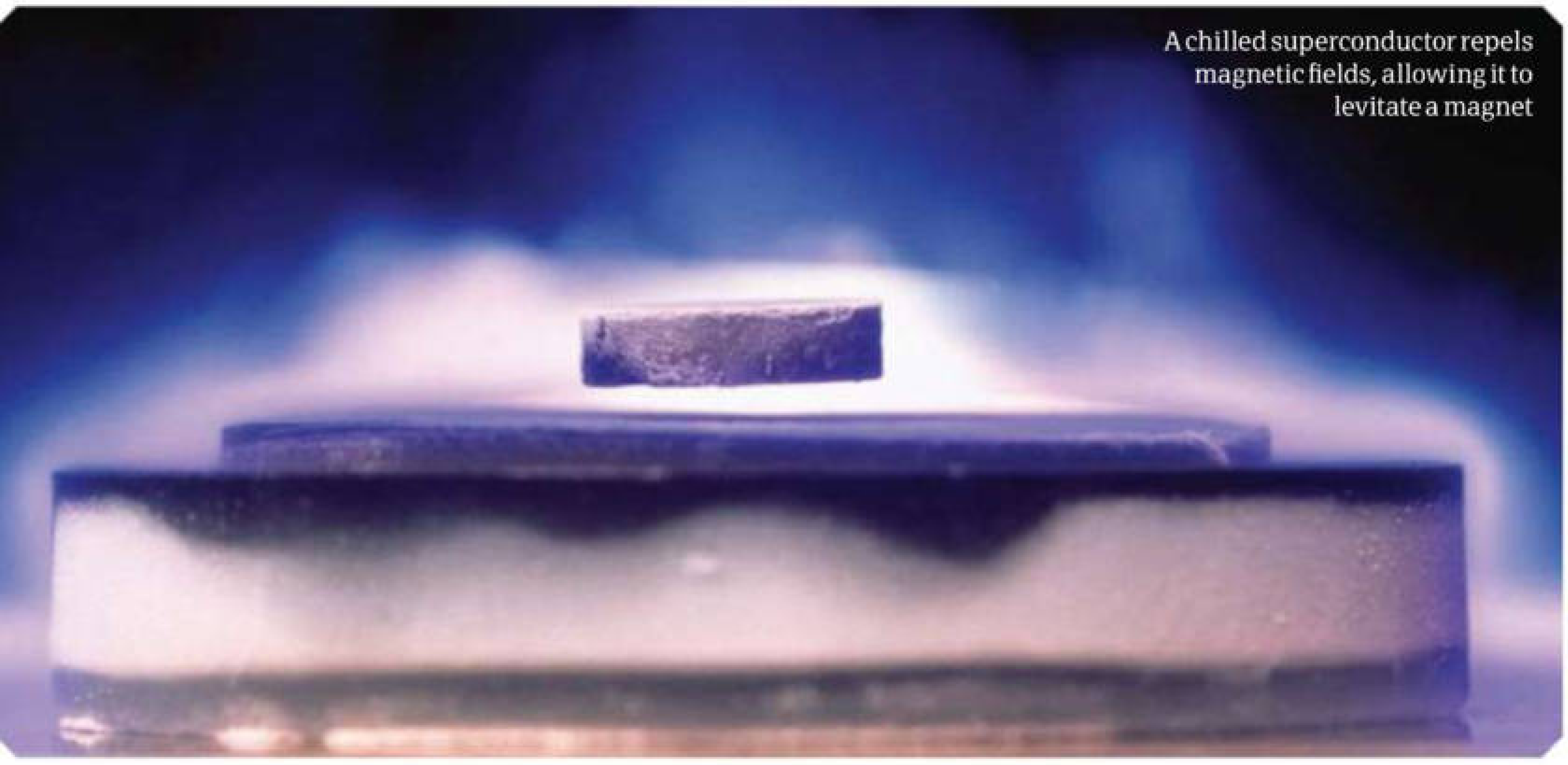
2. Bending the lattice
As a negatively charged electron makes its way through, the positively charged ions are attracted into its path.

3. Electrons are drawn in
This bend in the lattice creates an area of stronger positive charge, drawing another electron into the same space.

4. Electron pair
Trapped in a tight space, the two electrons are forced together despite their opposing negative charges.

5. Electron pairs unite
A quirk of quantum mechanics allows electron pairs to join forces as a Bose-Einstein condensate, known as a BEC.

6. No resistance
As a condensate, the cloud of electron pairs moves together in perfect unison, travelling unhindered through the superconductor.



A chilled superconductor repels magnetic fields, allowing it to levitate a magnet

1935
London brothers
Fritz and Heinz London reconcile superconductor theory to show that zero resistance and the Meissner effects both stem from the same phenomenon.

1957
BCS
Bardeen, Cooper and Schrieffer propose the eponymous BCS theory of superconductivity, explaining electron pairing. It earns them a Nobel prize.

1986
Hot stuff
Bednorz and Müller discover the first 'high-temperature' superconductor, which works its magic up to a high of -243°C (-405°F).

2009
Hotter stuff
Today's superconductivity temperature record is set by mercury barium calcium copper oxide, which acts as a superconductor up to a 'blistering' -138°C (-211°F).

The potential of superconductivity

Despite their impressive abilities, most current superconductor technologies remain chained to hi-tech science laboratories, burdened by bulky, energy-greedy and also very expensive cooling systems in order to function.

Scientists have, however, set their sights on creating a superconductor that works at room temperature, which could bring cutting-edge technologies into all of our lives. Inexpensive, portable MRI scanners could drastically improve healthcare, while superfast maglev trains would zip up and down the country, considerably reducing travel times.

Replacing our inefficient electrical grids with superconducting cables would slash our electricity bills and could even give renewable energies – such as wind farms – a much deserved boost. Elsewhere, superconductor-enabled electronics could see smaller, faster computers hit the high street.

While physicists can make superconducting materials operational at temperatures up to -138 degrees Celsius (-211 degrees Fahrenheit), the mechanism behind these is not yet understood. Many still believe that the Holy Grail of room temperature superconductors is achievable – it's just a matter of time and patience before we eventually discover it.

© SPL

The physics of football

Discover the science that lies behind taking the perfect free kick

The likes of David Beckham and Cristiano Ronaldo are known around the world for their expertise in the art of the free kick. Whether it's a curler into the top corner or a thundering piledriver, free kick taking is a vital part of the modern game. But how does science come into scoring the perfect goal?

The guiding principle is the Magnus effect. Investigated by German physicist Heinrich Gustav Magnus, this law of physics demonstrates that airflow is distorted around any spinning cylinder or sphere in a certain way.

If the ball is spinning anticlockwise, the left side of it will experience less drag as it moves in the same direction as the airflow, while the right side spins against the onrushing air, increasing the drag. This creates a pressure imbalance, with the right side of the ball experiencing higher pressure and the left side experiencing lower pressure. It is this imbalance which forces the ball to move to the area with lower pressure, thus curling to the left.

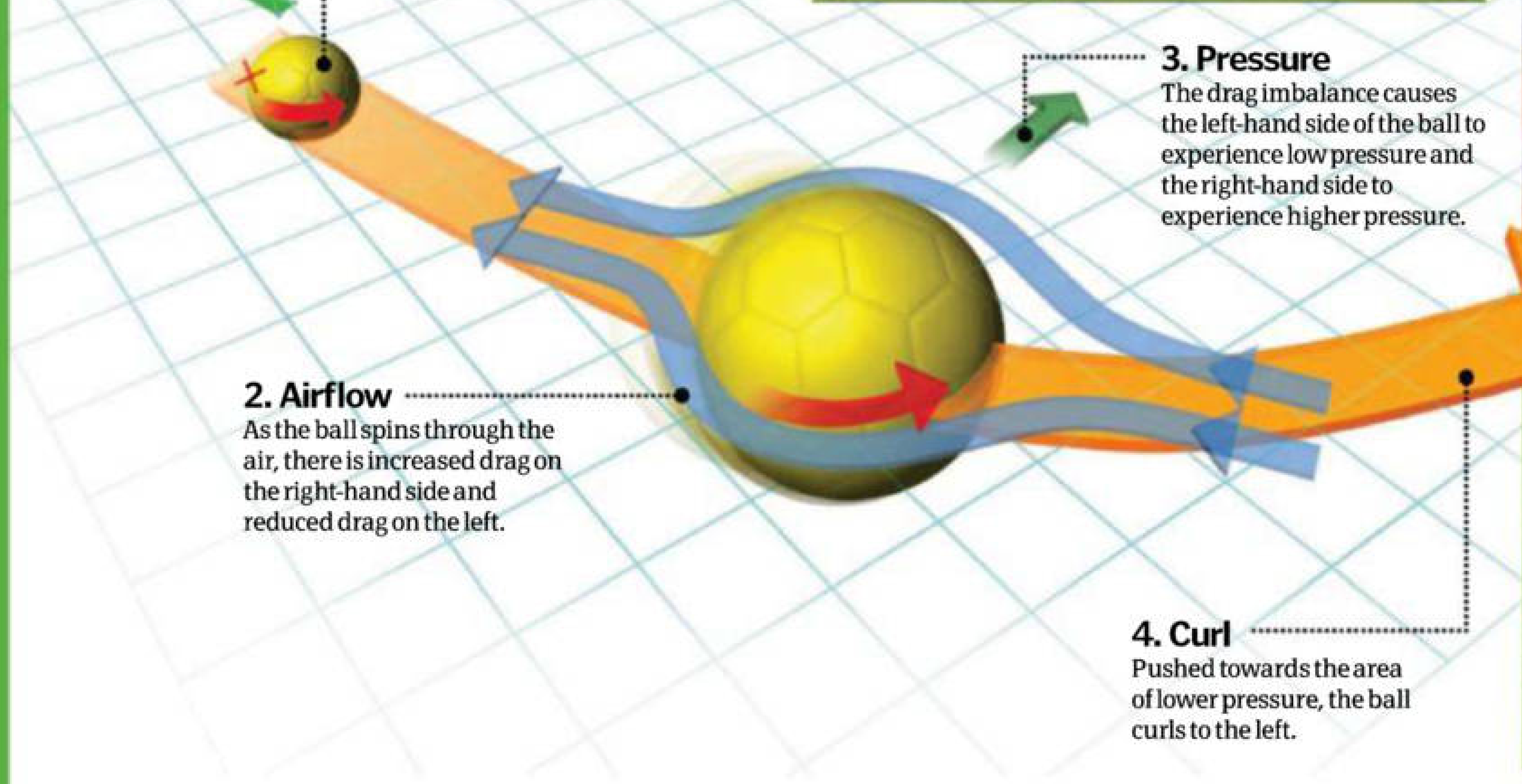
But the Cristiano Ronaldo or Gareth Bale style of free kicks is a whole different ball game. The idea behind the immensely powerful, swerving free kick is imparting as little spin as possible. As the air flows over the ball, a boundary layer is produced, which is a cushion of air that sticks very tightly to the surface of the ball. If an imperfection in the ball disrupts this airflow, it will deviate in the air.

A rapidly spinning football won't deviate much from its original course, but a ball hit flatly will, as it will have more time to move in the direction of the disruption. So when Ronaldo strikes the ball with little spin, any minor imperfection in the football will cause it to move during flight and outfox many a poor, bewildered goalkeeper.

Why footballs can be too round

The official match ball for the 2010 World Cup in South Africa, known as the Jabulani, caused consternation with goalkeepers and strikers alike. The lack of panels on the ball and the use of internal stitching made it the roundest ball ever. However, the roundness of the ball caused a lot of confusion among players because of its completely unpredictable swerving. Outfield players didn't like it because the lack of imperfections meant less grip between ball and foot, meaning that they struggled to impart spin on the ball. Meanwhile, goalkeepers couldn't anticipate the trajectory because it would have a habit of suddenly slowing mid-flight or ballooning up, a bit like a plastic inflatable ball.

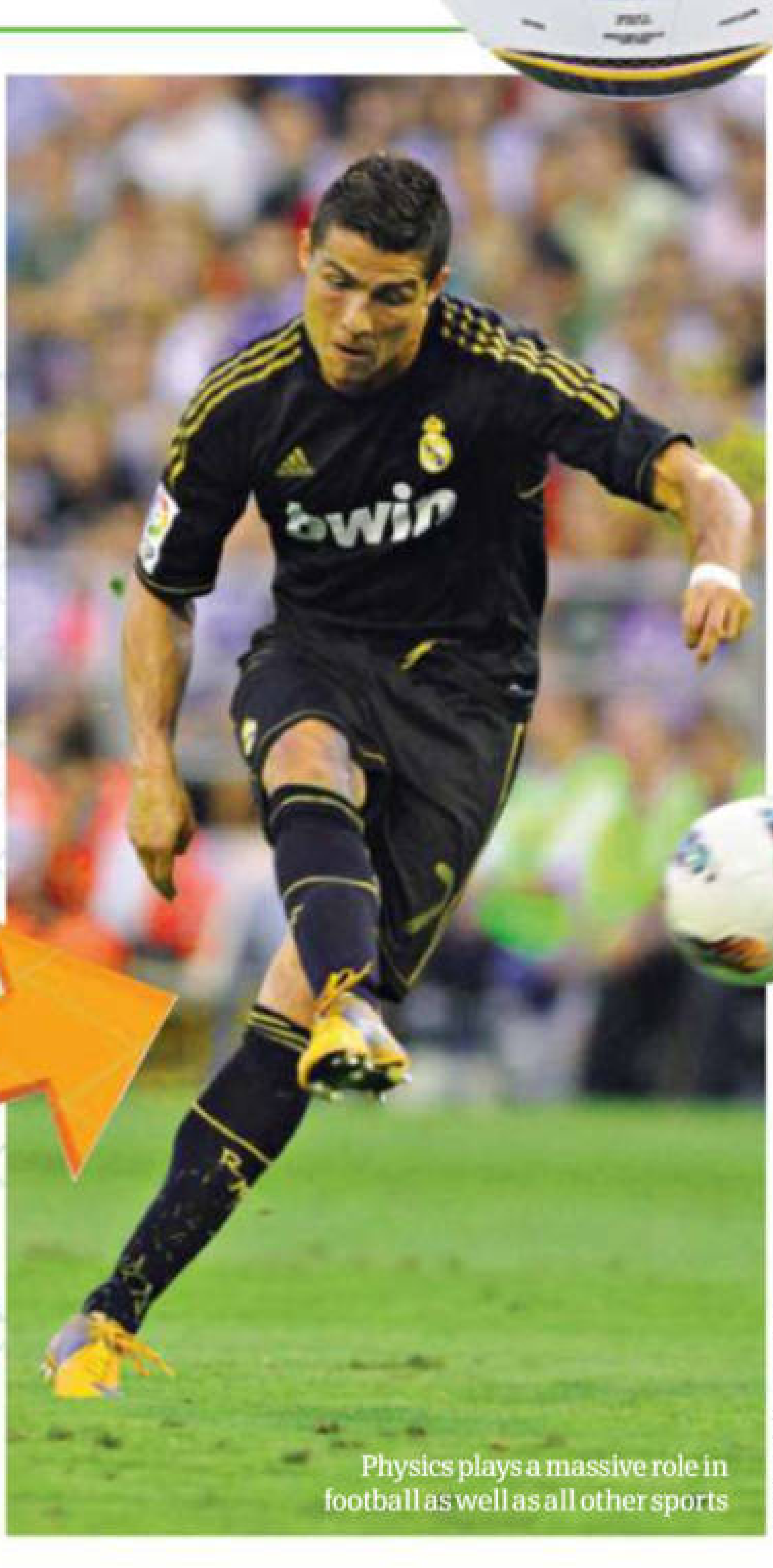
David Beckham made the art of the free kick one of his specialities


1. Kick
The player kicks the ball on the right-hand side, causing it to spin anticlockwise.

2. Airflow
As the ball spins through the air, there is increased drag on the right-hand side and reduced drag on the left.

3. Pressure
The drag imbalance causes the left-hand side of the ball to experience low pressure and the right-hand side to experience higher pressure.

4. Curl
Pushed towards the area of lower pressure, the ball curls to the left.


Physics plays a massive role in football as well as all other sports

© Adidas; DK Images; Getty

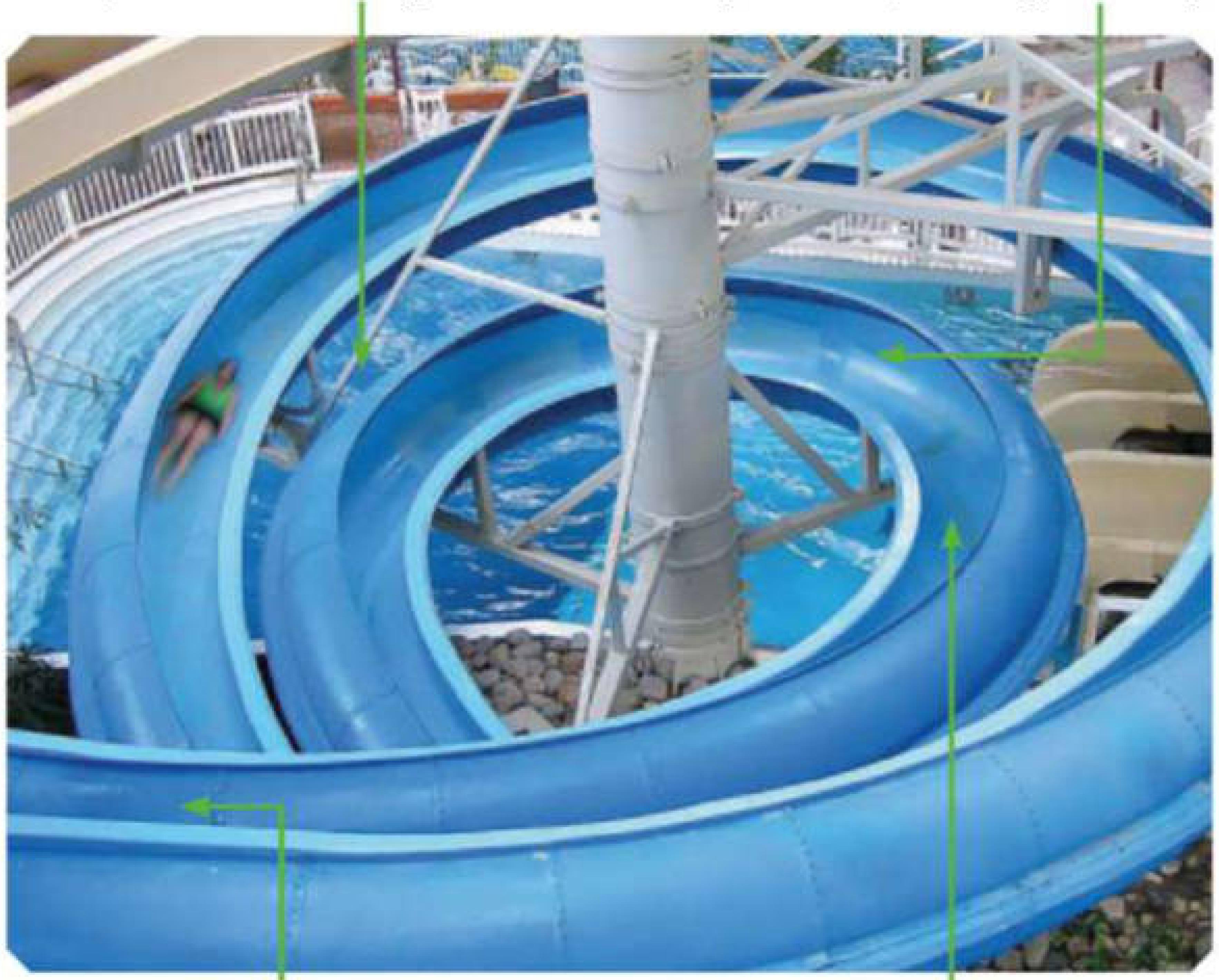
Water slides

Explaining the science behind these adrenaline-inducing attractions

Water slides work by exploiting the power of the Earth's gravity, the lubricating properties of water and the smooth, friction-reducing surface of artificial plastic and fibreglass composites, in order to generate necessary force and momentum to propel riders through their systems. Slide construction tends to be highly eccentric – tuned to maximise g-forces experienced – with riders funnelled down twisting fibreglass tubes or gullies from an elevated position which is typically between 10-40 degrees.

There are three main types of water slide: body slides, tube/raft slides and mechanical hydro slides. The former is the simplest design and relies merely on the relationship between the rider's mass and the effect of gravity to propel them, with their changing position aided by the plastic, and the fluid properties of water, which help to restrict the amount of friction. Tube/raft slides operate along the same principle of body slides but introduce an intermediary layer between the rider and the carrier – such as a rubber ring or foam sled – allowing for a greater speed and angle of attack when riding the attraction.

Mechanical hydro slides, while bearing a resemblance to and exploiting similar force-generating methods of both aforementioned slide types, are more complex constructions. Here, riders are propelled both downwards and upwards by a series of magnets and/or conveyor belts, which run exterior to or underneath the slide's water flow. These hydro-magnetic water slides utilise linear induction motors to propel the rider's inner tube (a necessity for this slide type) up inclines that would not be possible if just exposed to natural forces.



Terminate
Water slides terminate the rider's gathered momentum and speed by depositing them into a large body of water, which absorbs and disperses their kinetic energy.

Velocity
Aided by the plastic and the water's lubricating properties, the rider's potential energy is converted into kinetic energy as they travel down, increasing their velocity.

Potential
At the top of the water slide the rider has a large amount of potential energy due to their height relative to the ground.

G-force
Due to the eccentric design of the slide and increased acceleration, riders experience increased g-forces in bends and loops.

Whirlpools

The often deadly vortex explained

Whirlpools are formed by the rising and falling of fast-flowing water through ocean channels on the seabed. Due to this, tsunamis – as seen in Japan – are major whirlpool creators, with their massive waves receding quickly away from the shoreline. If this massive quantity of water is funnelled into narrow channels, a whirlpool can form, with a powerful vortex sweeping water towards its centre in a downdraught. While whirlpools can be dangerous, with rare cases of people drowning in them, there have been no reported cases of boats actually being sunk in their vortices.

Naruto whirlpools, located in the Naruto Strait channel

Rise and fall
Whirlpools are caused by the rising and falling motion of fast-flowing water through ocean channels.

Vortex
Water is swept towards the whirlpool's centre in a downdraught. Smaller examples of whirlpools can be seen in your bath at home and even in small ponds.

© Hellbury

The shockwaves created by a bursting balloon are made visible in this high-speed photo by adding talcum powder

Balloon-popping science

Find out why the properties of latex give bursting balloons their bang

Balloons are made of latex, a special type of polymer called an elastomer. If you were to look at latex under a powerful microscope you would see a tangle of long molecules resembling a plate of cooked spaghetti. Each molecule is linked to its neighbours by bonds called cross-links, forming a dense network. When pulled apart, these tangled molecules straighten out, but as soon as the tension is released they snap back to their original shape, lending latex its stretchy quality.

Inflate a balloon and the latex molecules stretch out, putting the balloon's skin under a large amount of tension. If you then jab the balloon with a needle, you create a tiny fault in the latex. The existing tension rapidly transforms this tiny hole into a big tear, ripping the balloon apart with an almighty bang.

Don't feel embarrassed if popping balloons make you jump – their deafening noise is caused by nothing less than a sonic boom. As the balloon tears, the resulting pieces of latex contract at great speed. The ends of each piece move so fast that they break the speed of sound in latex, sending a shock wave travelling through the material.

Sharp objects aside, any process that creates a weak point somewhere on the balloon makes it liable to pop, from a naked flame to a tiny spark caused by static electricity discharging. Latex also becomes weaker and stiffer over time, allowing faults to develop gradually. This explains why balloons sometimes seem to mysteriously burst of their own accord.

No bang theory

It might seem illogical but there is a way to pierce a balloon without it popping – discover how in this step-by-step…

1. Inflate the balloon

For this trick, use a good-quality, medium-sized balloon. Take a deep breath and inflate the balloon to full size – stretching the latex a little beforehand makes this easier. Then let out about a third of the air and tie a knot.

2. Prepare a skewer

Take a wooden skewer, making sure to pick a sharp one with no splinters which could tear the balloon. Dip the tip of the skewer in vegetable oil, which will act as a lubricant to reduce friction and help the point glide through the balloon's skin.

3. Pierce the balloon

Start at the bottom (beside the knot) as this is where the balloon's polymer molecules are stretched the least. Carefully push the skewer into the balloon where the rubber looks darkest. Gentle pressure will help, but don't jab yourself!

4. Out the other side

Gently push the skewer through the balloon, guiding it toward the opposite end. The latex here is also under less tension than elsewhere, so it can be pierced without bursting the balloon. Push the skewer until it emerges through the skin again.

5. Take a bow

Job done – although you should expect the trick to take a few attempts before you get it right. You can now remove the skewer from the balloon if you wish – it still won't pop at this stage but the air inside the balloon will leak out fairly fast.

© Alamy

How gravity works

Unravel the force that forms stars and keeps us on the ground

Of all Isaac Newton's revolutionary discoveries, perhaps none was more ambitious than unravelling the enigma of gravity. In the 1660s, Newton saw an apple fall to the ground and dared to ask, "Why?" Why doesn't the apple drift slowly upward? Why does water always seek the lowest place? Why does the Moon stay in orbit and not catapult into space? In his day, it was a question of near-religious significance.

Instead of meditating on divine mysteries, however, Newton drew up formulas. His law of universal gravitation, as presented in his 1687 treatise Principia, states that every particle of matter in the universe attracts every other particle of matter in the universe with a measurable force called gravity (named for the Latin 'gravitas', or weight). The strength of the gravitational force increases with mass and decreases with distance. In other words, the larger the object, the more gravity it exerts, and the closer you are to the object, the greater the pull.

Here's Newton's brilliantly simple formula for calculating the force of gravity between two objects, where m1 and m2 are the masses of the two objects, r is the distance between the two objects' centres of gravity, and G is the universal gravitational constant: $F = G\frac{m_1 m_2}{r^2}$

Perhaps the most surprising thing about Newton's law is its universality. Though it can be difficult to conceive, not only is there a gravitational attraction between the apple and the Earth, but there's also a gravitational attraction between you and the apple. Essentially, any two objects that have mass – whether cosmically huge like a galaxy or infinitely small like an atom – exert a gravitational force on each other.

If that's true, though, why don't we swerve toward the street when a large truck passes, or get pinned to the base of a skyscraper? Because that 'big G' in Newton's equation is actually incredibly small – roughly 6.67 x 10-11 Newtons (square metres/kilograms); yes, the decimal point is 11 digits to the left.

Unless the combined mass of the two objects is very, very large, the force of gravity between them is undetectable.

The Earth qualifies as a very, very large object with a mass of 5.97219 x 1024 kilograms (1.31664 x 1025 pounds). In comparison, your mass (not weight) is probably closer to 70 kilograms (154 pounds). If you plug the Earth's mass into Newton's equation as m1, your mass as m2, and then use the radius of Earth for r, you get an answer of 686 Newtons (154.2 pounds force).

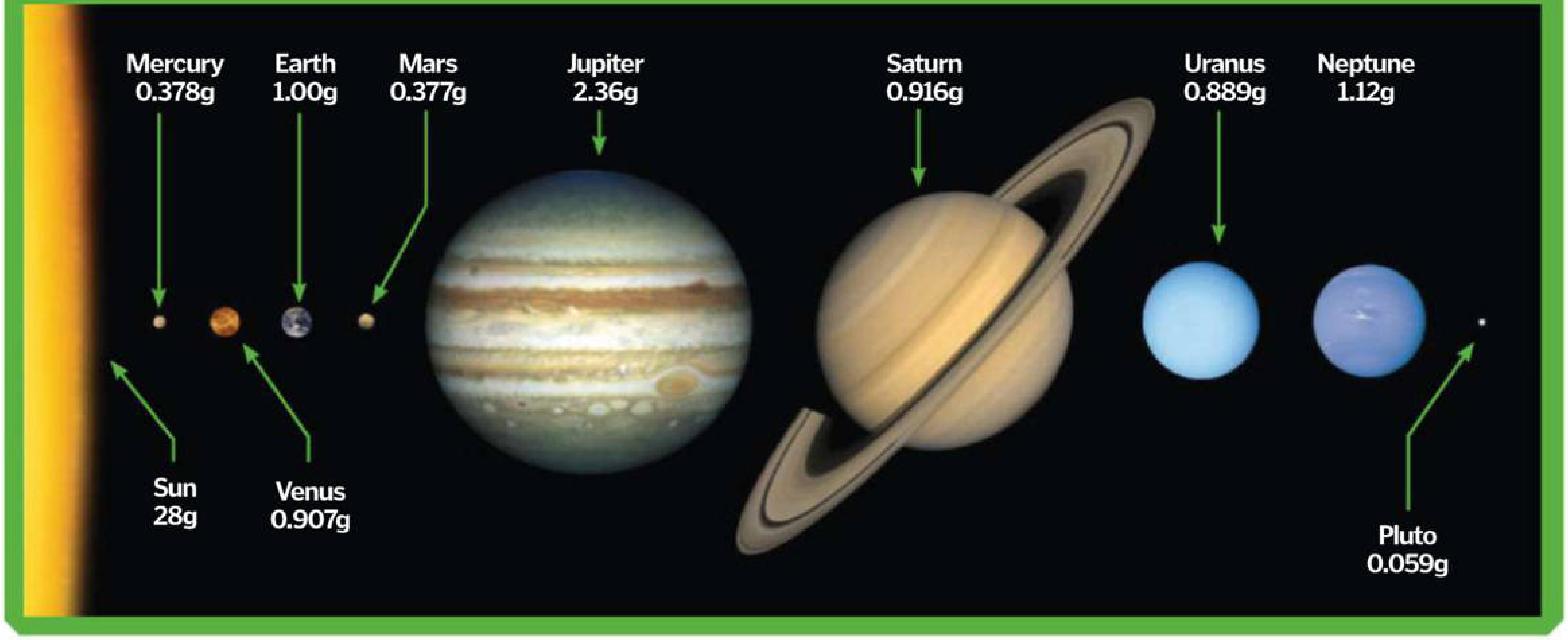
That is the gravitational force between you and our planet – in other words, the force that your mass exerts through gravity, aka your weight on the surface of the Earth. If you were to run the same numbers at a jumbo jet's cruising altitude of around 12,200 metres (40,000 feet) above sea level, however, you would actually exert a whole two Newtons less, because in this case there is a ▶

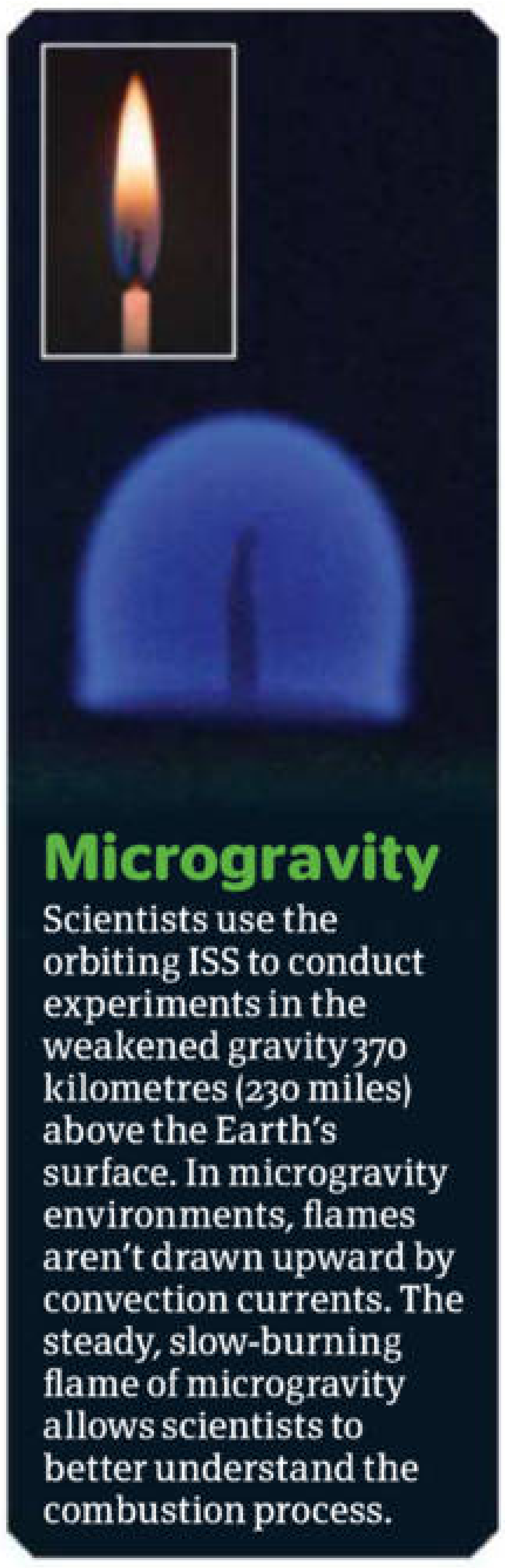
Gravity through the Solar System

As Newton theorised back in the seventeenth century, every particle of matter exerts a gravitational pull on every other particle of matter. If you concentrate a large amount of matter in one place, then it will create a much greater gravitational pull than a loose smattering of particles would do.

Mass is the measurement of how much matter there is inside a particular object. The greater the mass, then the more gravitational influence it will possess. Every planet, moon, star and galaxy in the universe has a different mass and therefore generates a unique gravitational pull that affects the celestial bodies around it.

The mass of the Earth pulls a falling object toward the ground at a rate of 9.8m/s^2 (32.2ft/s^2). In contrast, the mass of the Sun is 333,000 times greater than the Earth. As a result, a falling object near the surface of the Sun would be pulled downward at a rate approaching 274m/s^2 (899ft/s^2), 28 times faster than on our planet.



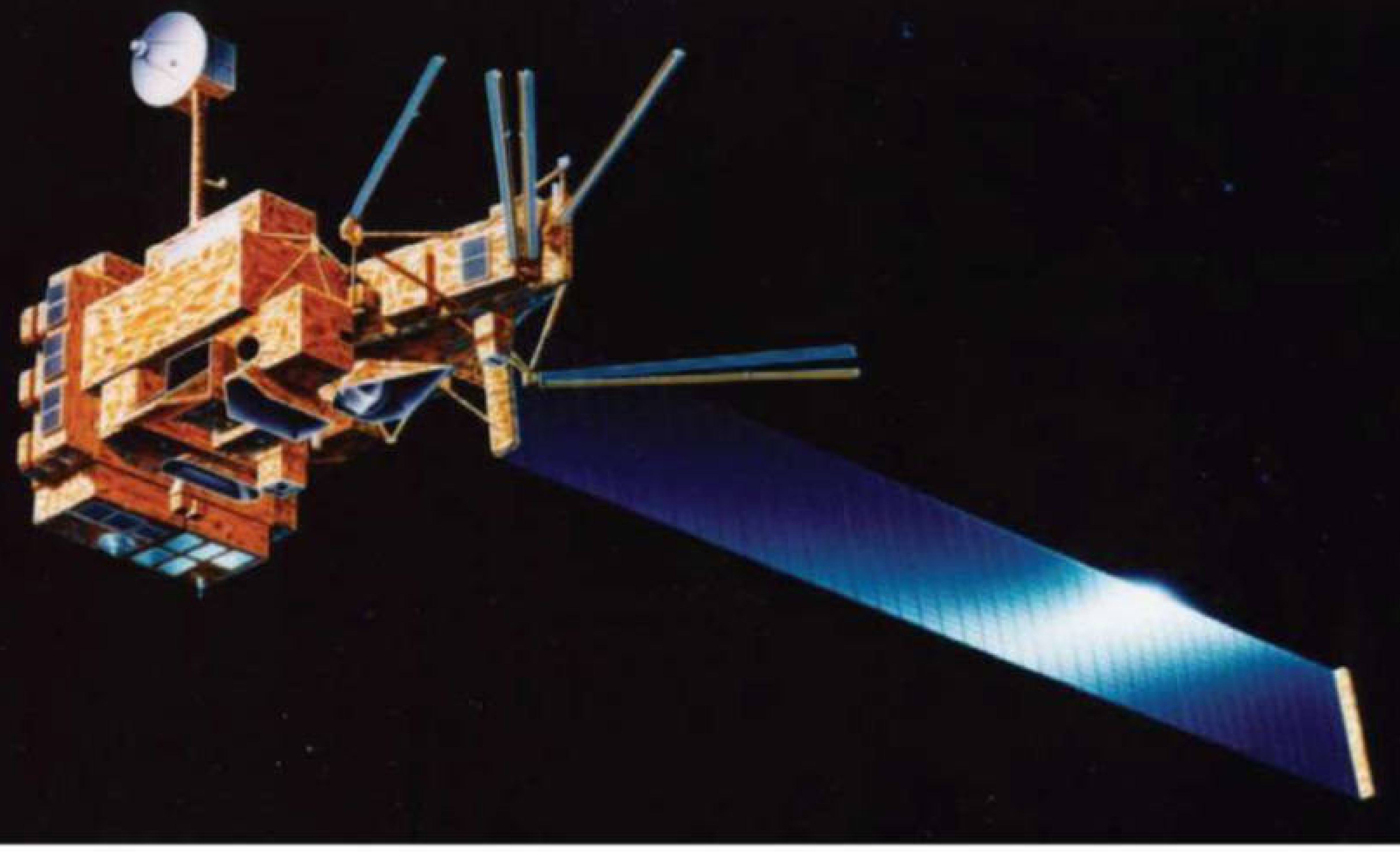


Microgravity

Scientists use the orbiting ISS to conduct experiments in the weakened gravity 370 kilometres (230 miles) above the Earth's surface. In microgravity environments, flames aren't drawn upward by convection currents. The steady, slow-burning flame of microgravity allows scientists to better understand the combustion process.

How orbits work

There are over 900 satellites currently orbiting the Earth. But how do they stay in orbit without any engines? Satellites in orbit don't require power because they're really in controlled freefall. A satellite is launched into space in the nose of a rocket. That rocket must provide enough thrust to escape the surface gravity. Once in space, the satellite is released on a perpendicular trajectory. But instead of flying away from the planet, the satellite 'falls' into an elliptical orbit that is determined by the long-distance gravitational pull of the planet.



© Thinkstock, NASA

▶ greater distance between your centre of gravity and the centre of the Earth.

Thanks to Newton's second law of motion, we know that force equals mass multiplied by acceleration (expressed as $f = ma$). Using Newton's gravity equation on page 42, we figured out the gravitational force between you and the Earth. Since we know the combined mass of you and the Earth, we can then solve the acceleration of gravity ($a = f/m$). The answer, $9.8m/s^2$ ($32.2ft/s^2$), is also known as 'little g'. Little g, like big G, is a constant, but it's only a constant for objects on or near the surface of the Earth. This means that little g on, say, the Moon or near the Sun is a whole different story.

Little g is critical as it explains why objects fall to the Earth at a consistent rate, even when they are of wildly different masses. For instance, if you push a BMW Sedan and a bowling ball off the top of the Burj Khalifa hotel in Dubai – currently the tallest building in the world – they will both hit the ground at exactly the same time. The exceptions are objects with low mass and a lot of surface area, like a feather or parachute, which float down slowly as the result of upward drag. This wouldn't be the case, however, in an airless environment – for example, a laboratory vacuum or the surface of the Moon – where, believe it or not, the feather and the bowling ball would fall at exactly the same rate.

Notice that gravity is the force of attraction between *two* objects; that is, it's a two-way process. Not only are you attracted to Earth with a force of 686 Newtons (154.2 pounds force), but the Earth is attracted to you with an equal force. In fact, if you fall out of a tree and accelerate toward the Earth at $9.8m/s^2$ ($32.2ft/s^2$), the Earth also accelerates towards you. But that's impossible, right? The world doesn't jostle out of orbit every time some klutz tumbles out of a tree. The difference is in the rate of acceleration. If $a = f/m$ and f is 686 Newtons, then the rate of acceleration gets slower and slower as mass gets bigger and bigger. Yes, the Earth technically accelerates towards you and every other falling object, but that rate of acceleration is so tiny – and the Earth's inertia and momentum so great – that no wiggle is remotely detectable.

While Newton's universal law of gravitation gives us the physics to calculate the force and acceleration of gravity just about anywhere in the universe, it doesn't explain what gravity is and how it works at an atomic level.

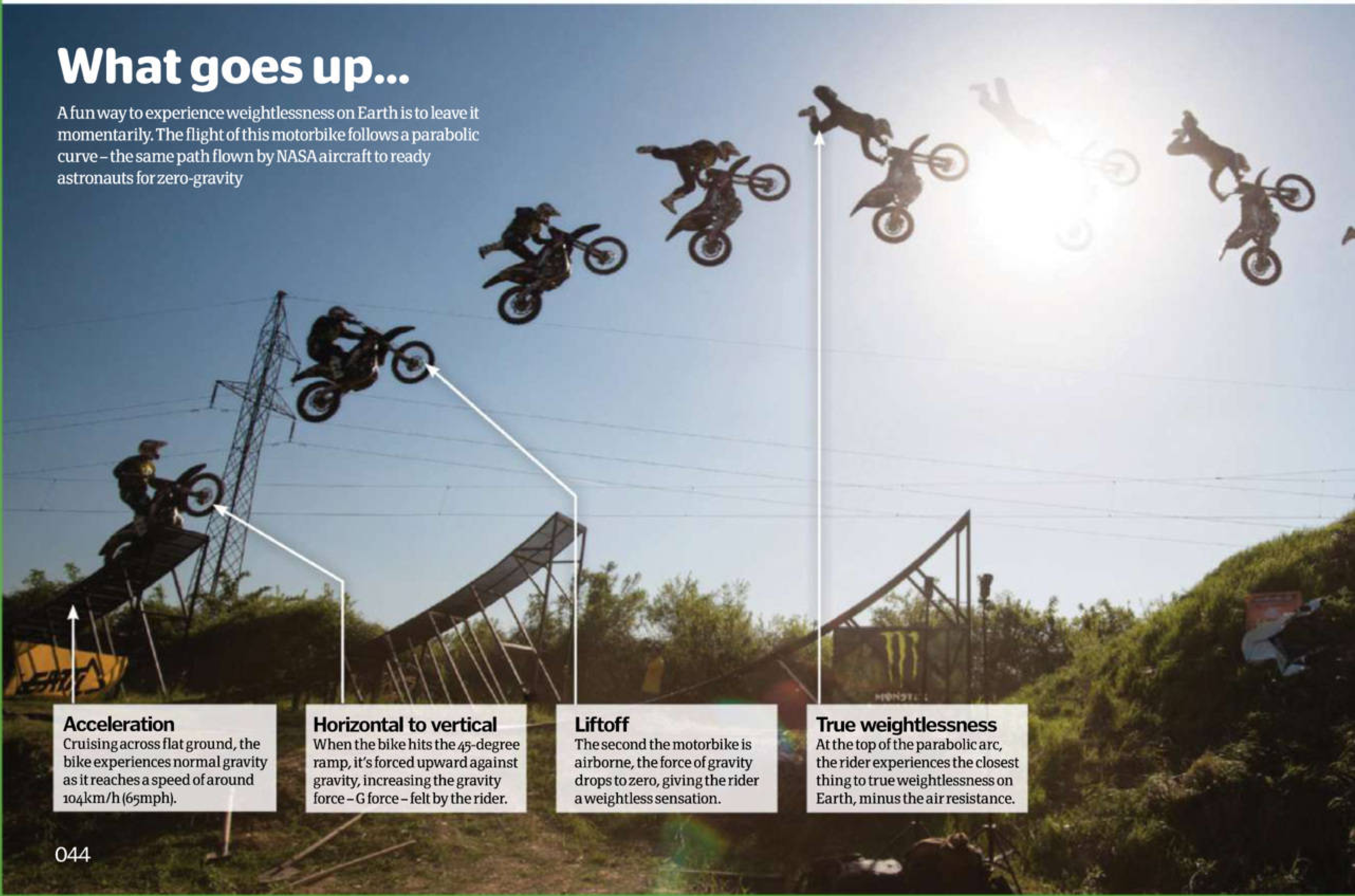
Albert Einstein took up that challenge with his general theory of relativity, published in the early twentieth century, which explained gravity as a curve in the space-time continuum. Beyond our three-dimensional universe, Einstein argues, is a fourth dimension of space and time. Objects with large masses, like planets, can warp the space-time dimension like a bowling ball on a trampoline. If you try to roll a marble across the trampoline, it will be drawn toward the bowling ball. The same is true for planets as they swirl in orbit around a huge celestial body like the Sun, or a cosmic beam of light that bends as it passes a black hole.

But even Einstein's revolutionary theory didn't explain the mechanism at work in gravity. What is it, exactly, that carries this force between two objects? Today, many physicists believe that the gravitational interaction is carried by undetectable, massless particles that are referred to as gravitons. Others talk of gravitational waves – barely detectable shockwaves of gravitational force created by the collision of neutron stars or the explosion of a supernova.

Despite the limits of our understanding, what began as an apple falling from a tree in the seventeenth century has led to some remarkable insights into the mysterious forces that guide the universe. Gravity, the force that keeps our feet firmly on the ground and dictates global tides with the passing of the Moon, appears to be the same ancient force that bound together primordial cosmic elements to form the first stars and galaxies. If nothing else, it's something to mull over the next time you're falling out of a tree...

What goes up...

A fun way to experience weightlessness on Earth is to leave it momentarily. The flight of this motorbike follows a parabolic curve – the same path flown by NASA aircraft to ready astronauts for zero-gravity



Acceleration
Cruising across flat ground, the bike experiences normal gravity as it reaches a speed of around 104km/h (65mph).

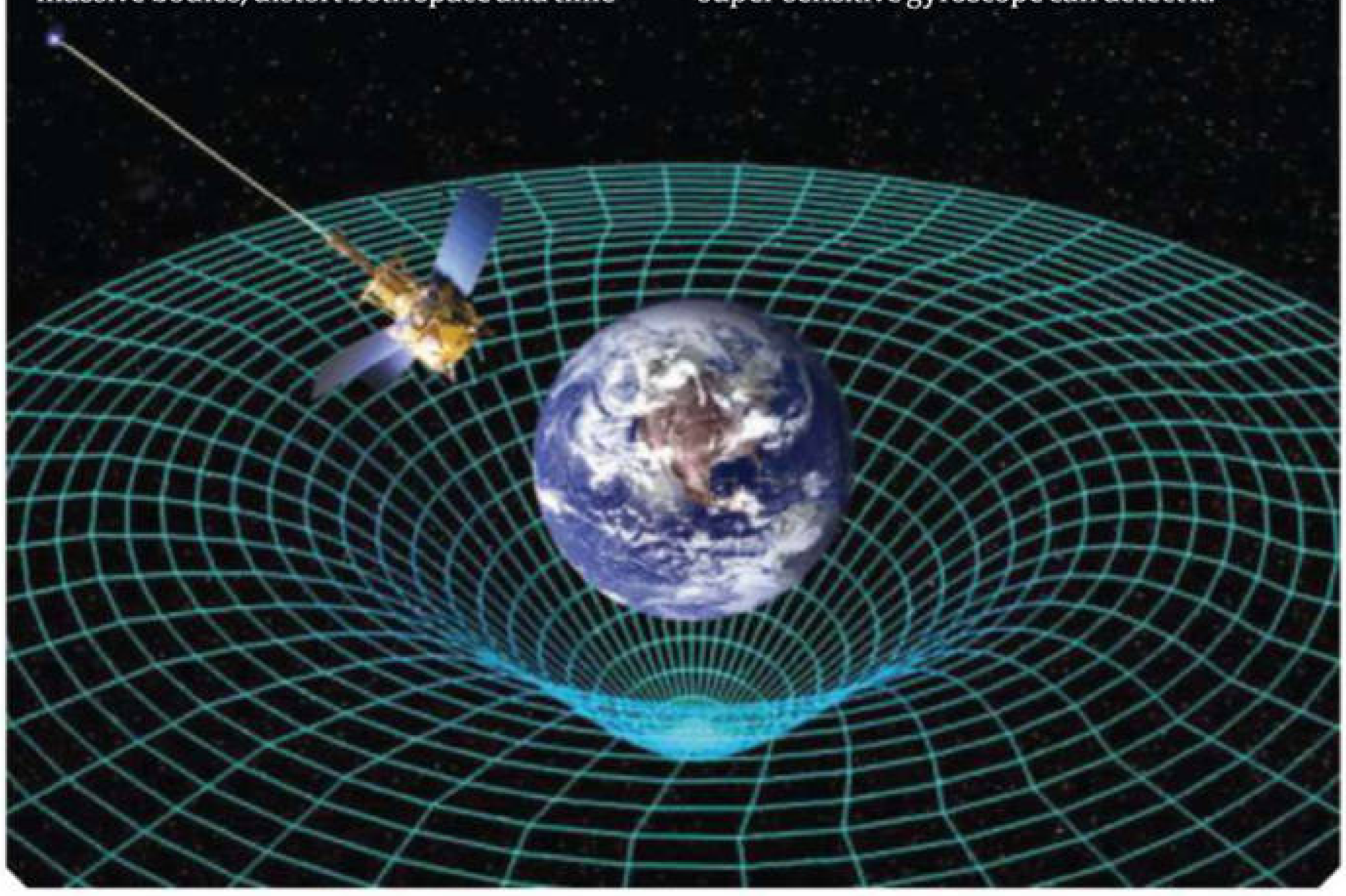
Horizontal to vertical
When the bike hits the 45-degree ramp, it's forced upward against gravity, increasing the gravity force – G force – felt by the rider.

Liftoff
The second the motorbike is airborne, the force of gravity drops to zero, giving the rider a weightless sensation.

True weightlessness
At the top of the parabolic arc, the rider experiences the closest thing to true weightlessness on Earth, minus the air resistance.

Gravity warps space and time

NASA's Gravity Probe B is being used to test Einstein's general theory of relativity. He said that large masses, such as planets and other massive bodies, distort both space and time – as seen in the framework below representing space-time. More mass means more warping and greater gravity, and Gravity Probe B's super-sensitive gyroscope can detect it.



Finding the centre of gravity

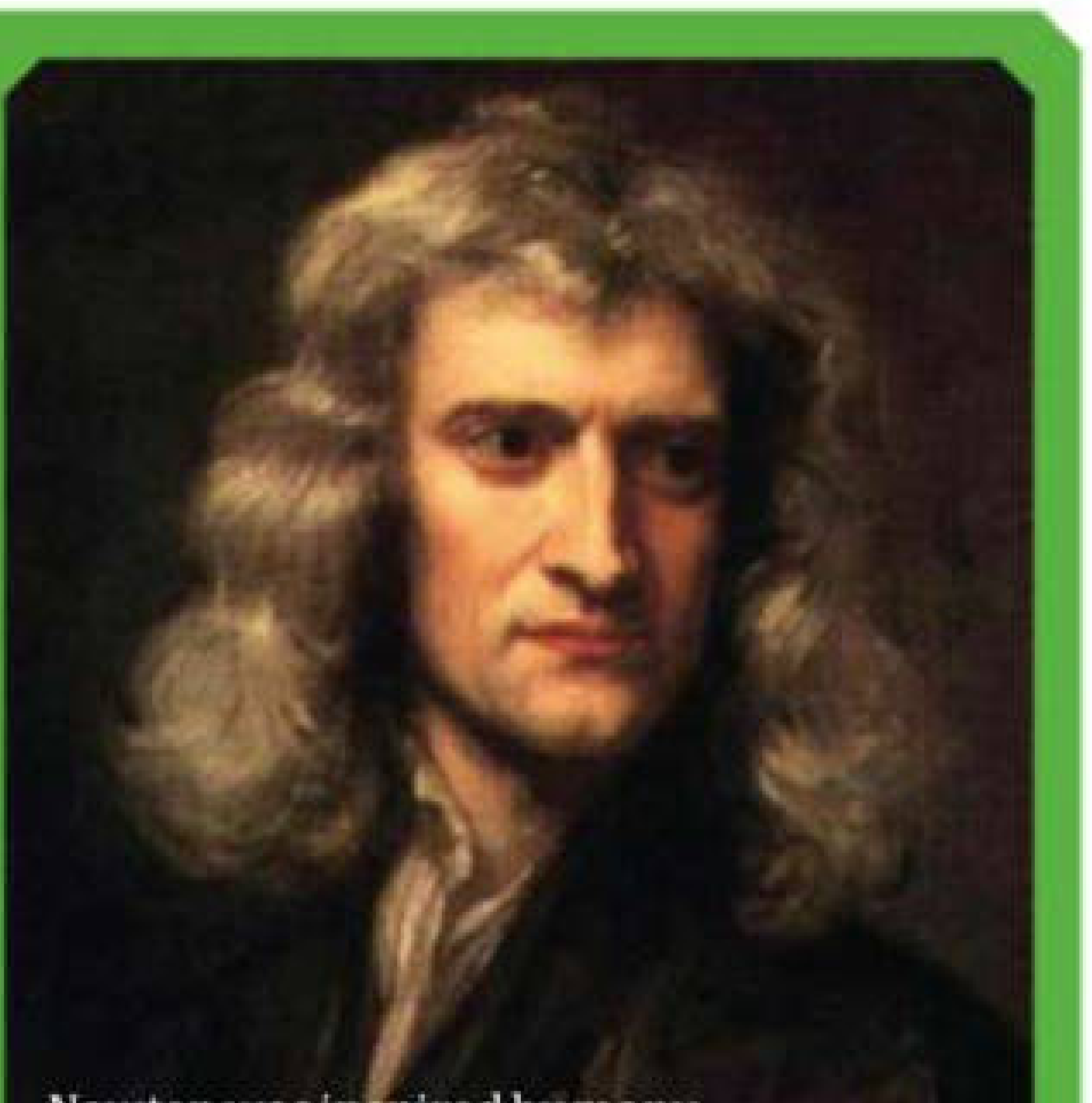
To calculate the acceleration of gravity, you need to know the distance between the centres of gravity of object one and object two. But how do you work out these centres of gravity? For the Earth, the centre of gravity is the exact centre of the sphere. The distance, then, between your centre of gravity and the Earth's centre of gravity is equal to the Earth's radius.

Coming down
With a take-off speed of 104km/h (65mph), a bike launched from a 45-degree ramp travels 22m (70ft) before gravity pulls it to Earth.

Landing
On the bike's landing, the rider experiences greater than normal gravity. An inclined landing ramp decreases the G force.

Measuring gravity

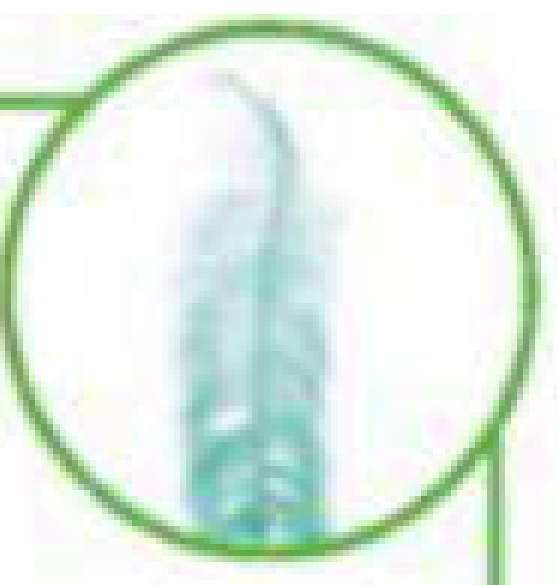
Thanks to Newton, gravity is a measurable force. Not coincidentally, the international standard unit of force is called a Newton (N). On Earth's surface, roughly 0.98N equals the downward force of gravity on 100 grams of mass. Likewise, one kilogram of mass exerts a downward force of 9.8N. To calculate the force of gravity, physicists use the formula f = ma (force = mass x acceleration). Since the acceleration of gravity is 9.8m/s^2 on Earth – ie little g – we can easily calculate the Newton force of any mass. The average person's mass is 70 kilograms, which multiplied by 9.8 gives you 686N – the force by which gravity keeps us all securely grounded.



Newton was inspired by many scientists including Robert Boyle, Simon Stevin and René Descartes

> "Every object has the same acceleration of gravity near Earth"

A hammer vs a feather



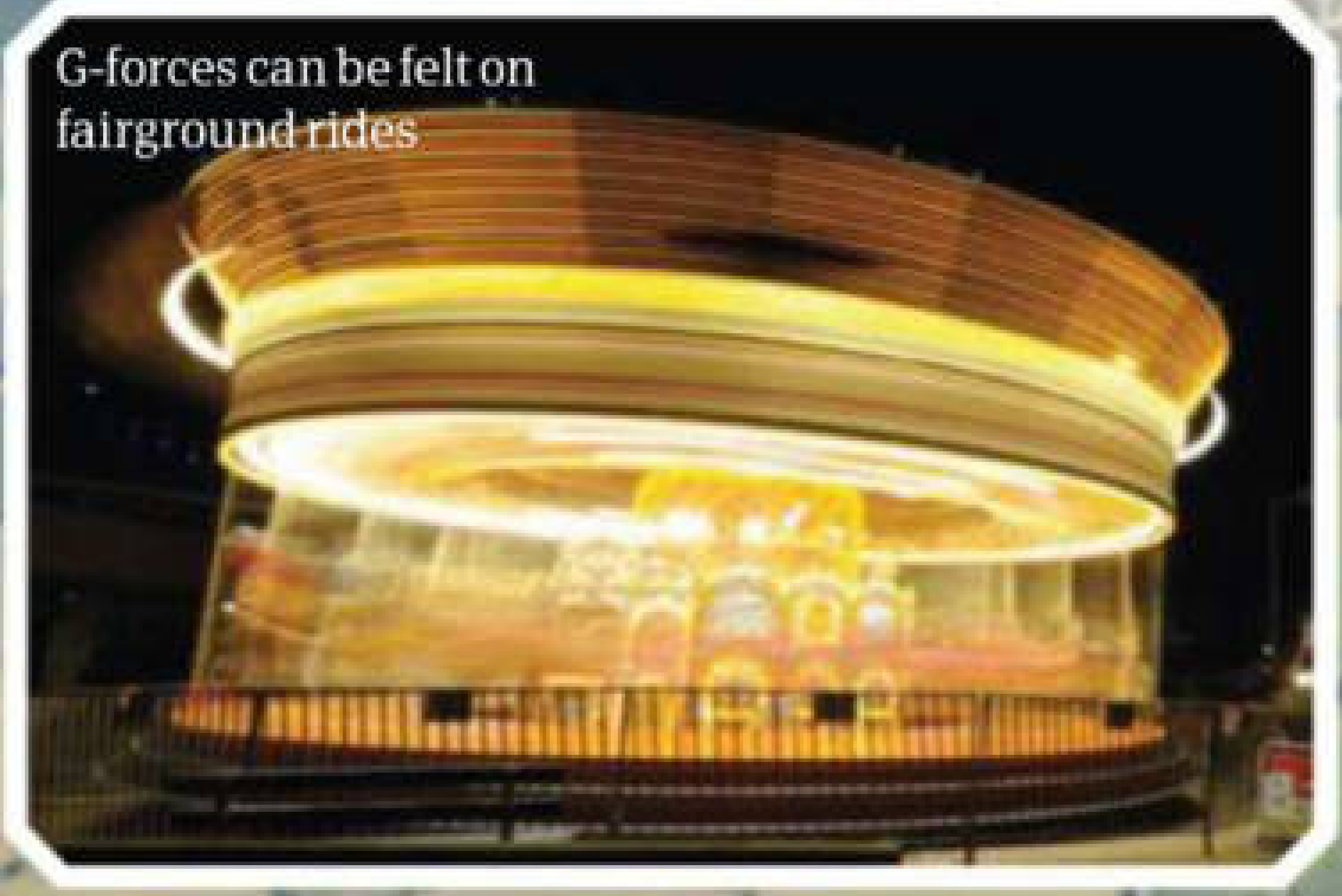
Newton's law of universal gravitation states that an object with greater mass will exert a greater gravitational force. But force is not the same as acceleration. The question of which object lands first is a matter of acceleration. When you do the maths, you find that every object – regardless of its mass – has the same acceleration of gravity near the Earth's surface. Take a look:

$$a = f/m;\ \text{or}\ a = (m \times 9.8\text{m/s}^2)/m;\ \text{or}\ a = 9.8\text{m/s}^2$$

The only reason the feather falls slower on Earth is air resistance. In a perfect vacuum like space, in contrast, the feather and the hammer land at precisely the same time.

He's smiling now, but wait until he realises he left his parachute in the plane…

© Thinkstock



G-forces can be felt on fairground rides

Not a good time to have a blackout…

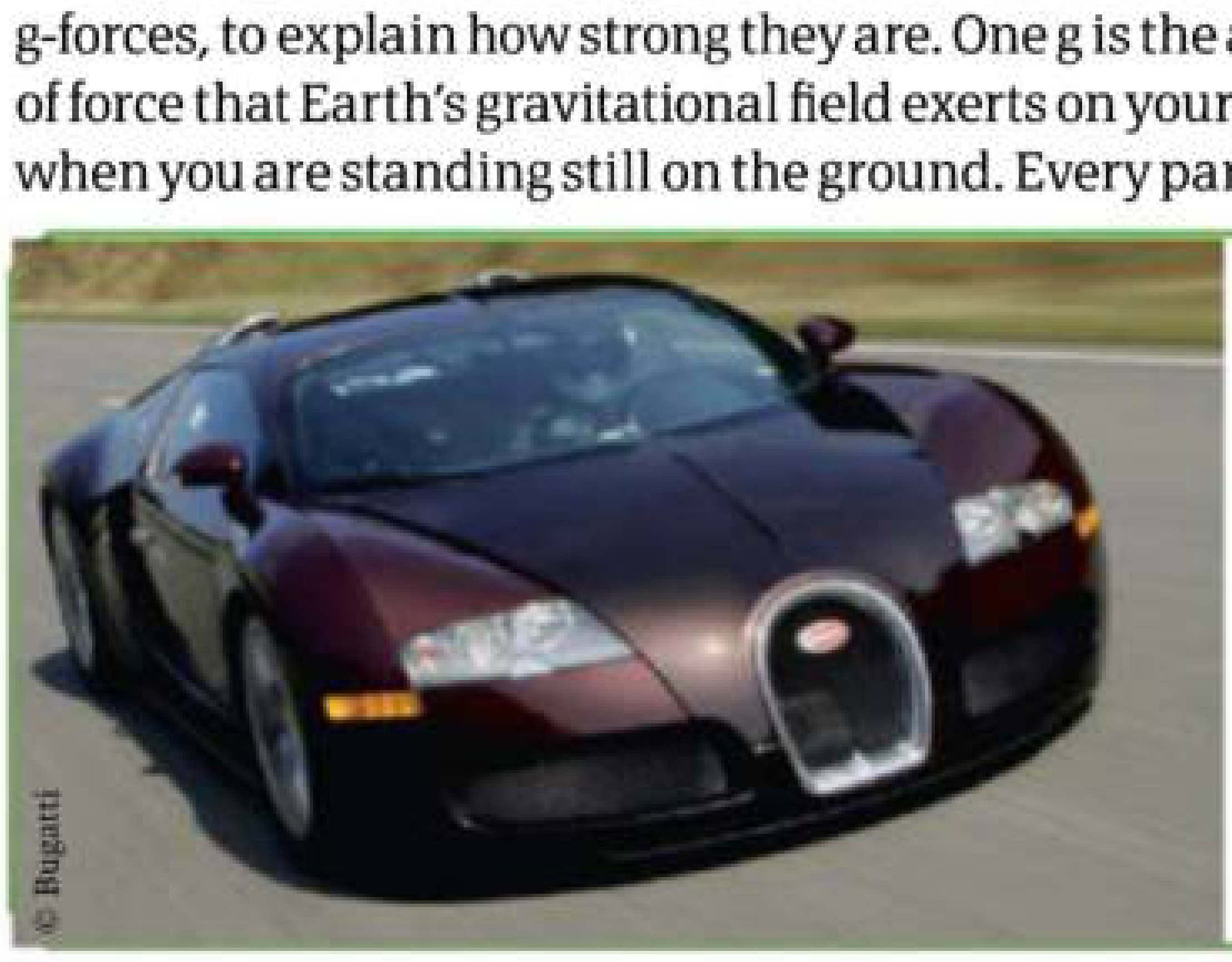
G-force explained

Intense acceleration in fast cars, fighter planes, rockets and roller coasters

When you're hurtling down the steel track of a roller coaster, it might seem that your stomach is climbing into your throat, and your eyes are squishing deep into your skull. Several forces are at play when you feel that way. Earth is constantly pulling down on every one of us. It has a great deal of mass, and that gives it a large gravitational field. And when we take a sharp turn on a fast ride, blast off in a rocket, or slam on the brakes, we're thrown around by forces far stronger than Earth's gravity. But why?

Engineers rate those experiences with numbers called g-forces, to explain how strong they are. One g is the amount of force that Earth's gravitational field exerts on your body when you are standing still on the ground. Every particle that makes up our planet is tugging on you simultaneously. Each one of those pulls is quite weak, but combined they are strong enough to keep your feet on the ground. Five g acceleration, something that race car drivers regularly experience, is five times as intense. Any time that an object changes its velocity faster than gravity can change it, the forces will be greater than one g. At zero g, you would feel weightless. And past 100g, you're almost certainly dead. Forces that intense can crush bones and squash organs.

Gravity is not the only source of g-forces. They take hold whenever a vehicle, like a car or a plane, suddenly changes its velocity. Speed up, slow down, or make a turn, and your velocity will change. The faster it happens, the more force you will experience.



© Bugatti

Understanding g-forces

To find out how many gs you experienced during an intense acceleration, take your maximum speed, divide it by the time it took to hit that rate, and then divide by 9.81m/s². The resulting number is how many gs you experienced.

Example: Put the pedal to the metal in a Bugatti Veyron and you will go from 0-100kph in 2.3 seconds.

100kph is 28m/s, 28 / 2.3 = 12m/s², 12 / 9.8 = 1.2g

What a knockout

If you are riding in a jet while it is making sharp turns, the blood in your head may rush out into your lower body. As the plane turns, all of the fluids in your body will act as if they were in a centrifuge, moving toward your feet, or whatever part of your body is on the outer edge of the turn. When that happens, your eyes will not get enough oxygen and you may experience a greyout, a sudden loss of colour vision, or a full blackout, with temporary blindness. Accelerate harder and you will lose consciousness as blood retreats from your brain, depriving it of oxygen. Some people will experience these effects below 5g, but seasoned fighter pilots can take a bit more because they are very physically fit. They train themselves to resist the forces, and wear special suits that squeeze blood up into their heads.

Acceleration

The relationship between acceleration and velocity is more complex than it first appears

Acceleration is the rate of change of velocity over time, with velocity being the rate of change of position. However, their relationship is not constricted, as is commonly understood, to merely increased mono-directional movement. This is because velocity is a vector physical quantity, requiring both speed and direction to define it. So absolutely any change in speed – including a decrease – is classed as acceleration, as is any change of directional motion, regardless of a speed increase or decrease. Therefore, it is not only a supercar that accelerates from 0-60, but also a spinning globe, dropped ball and rotating compass.

To attain an object's acceleration its velocity should be divided by time, or in unit terms, by dividing metres per second by seconds. So if a ball is thrown across a room at a velocity of six metres per second into a container, and the whole action takes three seconds, then the ball's acceleration would be six divided by three and therefore two metres per second.

However, as acceleration is a vector quantity (measured against both the rate of change in speed and direction), this figure is then squared to achieve the full measurement of 2m/s2. It is important to note, however, that acceleration can be measured as both average acceleration and instantaneous acceleration, the former being velocity divided by time, while the latter acceleration at any given point in time.

Acceleration can also be measured against gravity, symbolised by the unit g, that in some situations is a convenient benchmark where variations can be juxtaposed against it. For example, Earth's gravity is 1g, roughly 9.8m/s2, and if you drop an apple from your hand to the floor it accelerates at that speed.

Rollercoasters increase and vary g from the natural 1g we are used to. This is why when riding a rollercoaster you can feel increased and decreased pressure on your body and also why, despite travelling often at no greater speed than 30mph, rides feel dangerous and fast.

Rollercoaster acceleration is typically measured against gravity, symbolised by the Roman unit g

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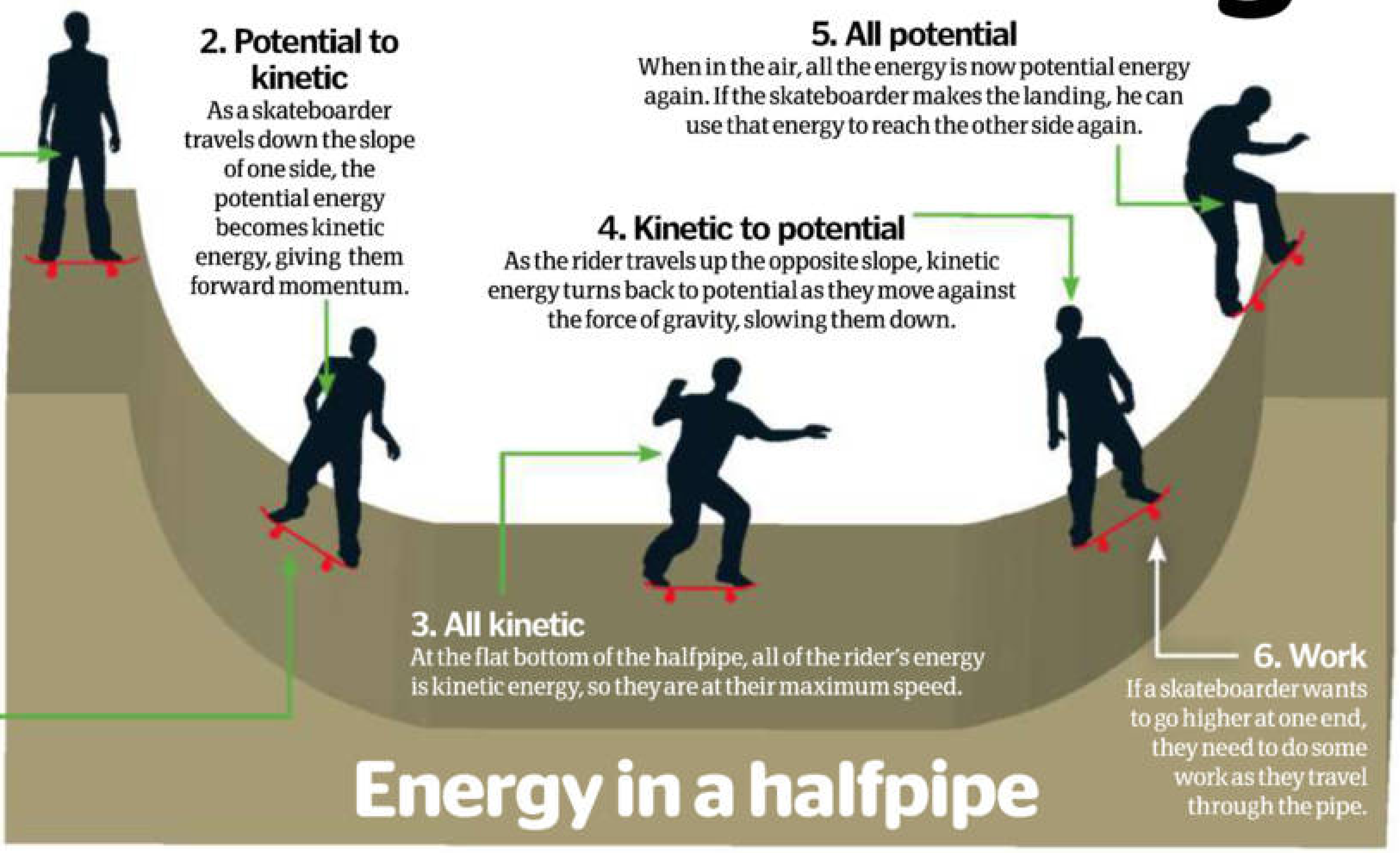
The science of skateboarding

Kick, twist and grab your way through the physics of half pipes

In a halfpipe, a skateboarder will typically start at one end (deck), then roll down into the flat of the halfpipe. They carry enough speed and momentum to shoot up the other side, gaining 'air' to perform tricks before landing again in the bowl of the halfpipe.



Energy in a halfpipe

1. Potential energy
At the deck of the halfpipe, before the skateboarder jumps into the halfpipe, they have a certain amount of potential energy, the result of gravity pulling them down.

2. Potential to kinetic
As a skateboarder travels down the slope of one side, the potential energy becomes kinetic energy, giving them forward momentum.

3. All kinetic
At the flat bottom of the halfpipe, all of the rider's energy is kinetic energy, so they are at their maximum speed.

4. Kinetic to potential
As the rider travels up the opposite slope, kinetic energy turns back to potential as they move against the force of gravity, slowing them down.

5. All potential
When in the air, all the energy is now potential energy again. If the skateboarder makes the landing, he can use that energy to reach the other side again.

6. Work
If a skateboarder wants to go higher at one end, they need to do some work as they travel through the pipe.

7. Pumping
The skateboarder crouches on entry to the flat and rises as they go upwards, tightening their radius of travel in the 'circle' and increasing their linear momentum.

The power of MAGNETISM

This invisible force allows the production of super-powerful electromagnets and everyday items such as credit cards, but what does it mean to be magnetised?

Magnetism is the force of nature responsible not only for our ability to live on a rock floating through space, but also for major technological achievements that have advanced the human race like never before. Our computers rely on them, our livelihood on Earth depends on their principles and our greatest science experiments use the most powerful magnets ever created by man. Were it not for magnetism we simply would not exist, and indeed without discovering the power of this fundamental force of nature, our life on Earth would bear no resemblance to what it is today.

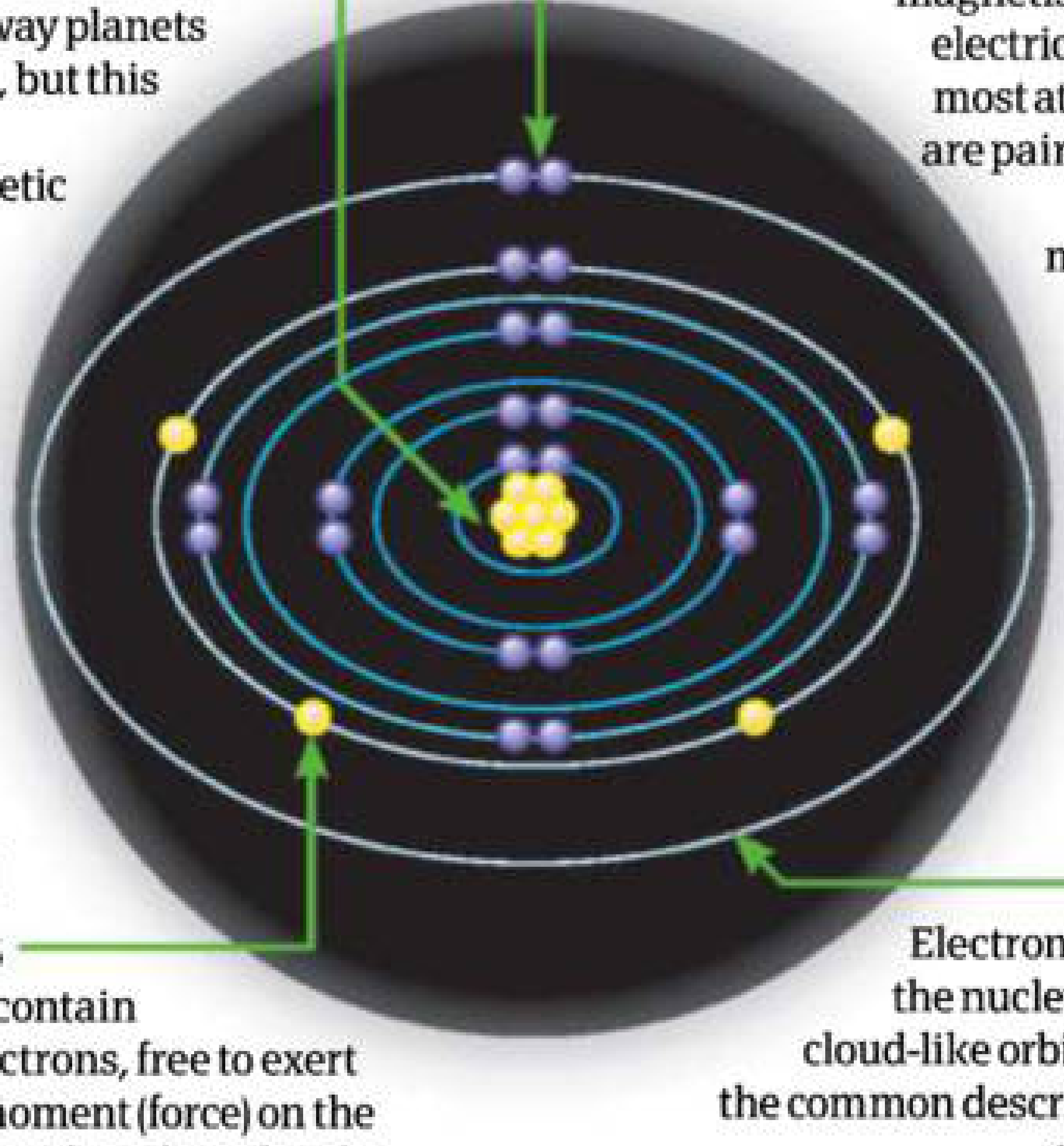
Scientists over the years have employed magnetism in new and innovative ways, delving into realms of particle physics otherwise unexplored, but let's take a look at how basic magnets are made. It's fairly common knowledge that objects can be magnetised, making them stick to other magnetic objects, and we know that things such as a fridge or horseshoe magnet always have magnetism. To make permanent magnets like these, substances such as magnetite or neodymium are melted into an alloy and grounded into a powder. This powder can be moulded into any shape by compressing it with hundreds of pounds of pressure. A huge surge of electricity is then passed through it for a brief period of time to permanently magnetise it. Typically, a permanent magnet will lose about one per cent of its magnetism every ten years unless it is subjected to a strong magnetic or electric force, or heated to a high temperature.

Now let's take a look at the magnets themselves, and what's in and around them. Surrounding every magnet is a magnetised area known as a magnetic field that will exert a force, be it positive or negative, on an object placed within its influence. Every magnet also has two poles, a north and south. Two of the same poles will repel, while opposite poles attract. Inside and outside a magnet there are closed loops known as magnetic field lines, which travel through and around the magnet from the north to south pole. The closer together the field lines of this magnetic field are, the stronger it will be. This is why unlike poles attract – the magnetic forces are moving in the same direction, so the field lines leaving the south of one magnet have an easy route into the north of another, creating one larger magnet.

Conversely, like poles repel as the forces are moving in opposite directions, hitting one another and pushing away. It's the same effect as other forces. If you push a revolving door while someone pushes from the other side, the door stays still and your forces repel. If you push in the same direction,

Magnetic atom

So what's the difference between the atoms of magnetic and non-magnetic elements? Well, the main difference is the appearance of unpaired electrons. Atoms that have all their electrons in pairs can't be magnetised, as the magnetic fields cancel each other out. However, atoms that can be magnetised have several unpaired electrons. All electrons are essentially tiny magnets, so when they are unpaired they can exert their own force – known as a magnetic moment – on the atom. When they combine with electrons in the other atoms, the element as a whole gains a north and south pole and becomes magnetised.



Nucleus
Electrons of an atom orbit around the nucleus in the same way planets orbit the Sun, but this is due to the electromagnetic force and not gravity.

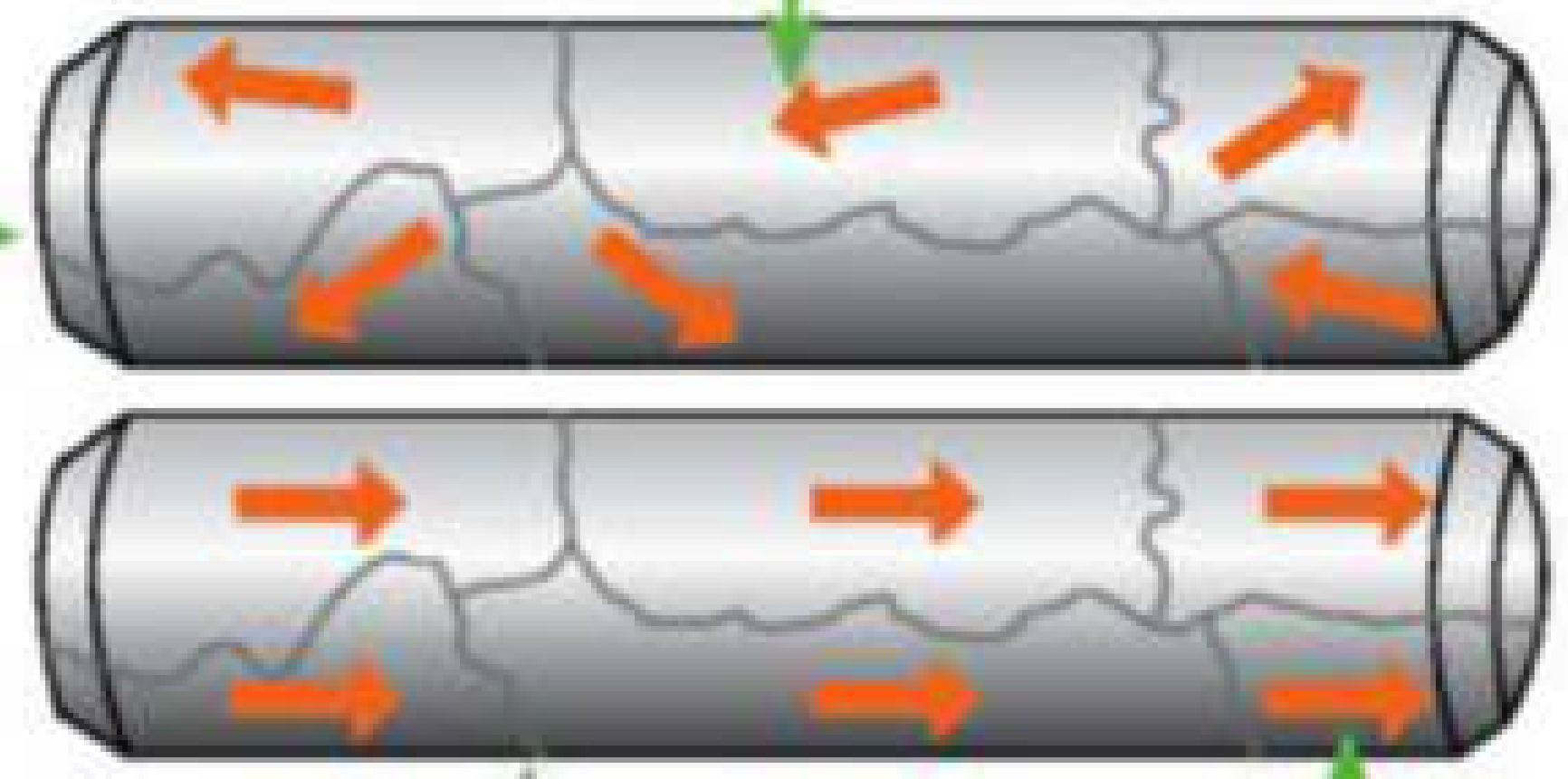
Paired electrons
Moving electrons create magnetism due to their electric charge, but in most atoms electrons are paired and there's no resultant magnetic force.

Unpaired electrons
Some atoms contain unpaired electrons, free to exert a magnetic moment (force) on the atom with a north and south pole.

Shells
Electrons travel round the nucleus in shells, in cloud-like orbits rather than the common description of them as rigid circles.

Inside a magnet

An object that can become magnetic is full of magnetic domains, which are chunks of about one quadrillion atoms each. When the object is magnetised, the domains line up to and point in the direction of the magnetic field now present. This is why a magnetic object is sometimes stroked with a magnet to magnetise it. It aligns the domains in one direction, so that a magnetic field can flow around the material.



Unmagnetised
With no magnetism, the object does not have a north and south pole, so there is no magnetic field present to align the domains.

Scattered
When a substance that can be magnetic is unmagnetised its domains go in random directions, cancelling each other out.

Magnetised
Introducing a magnet or electric current to the substance makes the domains all point in the same direction, with a magnetic field running from the north to south poles.

Aligned
When the domains are lined up, the substance as a whole becomes a magnet, with one end of it acting as a north pole and the other a south.

An electronic motor relies on magnets

© Thinkstock

however, the door swings round and you eventually end up back at your starting point.

The defining feature of magnetic poles is that they always occur in pairs. Cut a bar magnet in half and a new north and south pole will instantly be created on each of the two new magnets. This is because each atom has its own north and south pole, which we will talk about later. However, the obvious question is why the poles are there in the first place. Why do magnets have to have these field lines moving from north to south? The answer involves magnetic domains. It is best to picture a magnet as smaller magnet chunks put together. Each chunk (or domain) has its own north and south pole and again, as explained before, magnetic field lines travel from north to south. This means that all the domains stick together, with their forces concentrated in the same direction. They combine to make a larger magnet, exactly the same effect as when two magnets are stuck together. Each domain has about 1,000,000,000,000,000 (one quadrillion) atoms, while 6,000 domains are approximately equivalent to the size of a pinhead. Domains within a magnet are always aligned, but elements such as iron that can become magnetic initially have their domains pointing in random directions when the iron is unmagnetised. They cancel each other out until a magnetic field or current is introduced, making them point in the same direction and magnetising the iron, which creates its own new magnetic field.

To really understand magnets, though, we need to get into exactly what is happening inside these domains. For that, we need to get right down into the atom. Let's take ▶

Types of magnetism

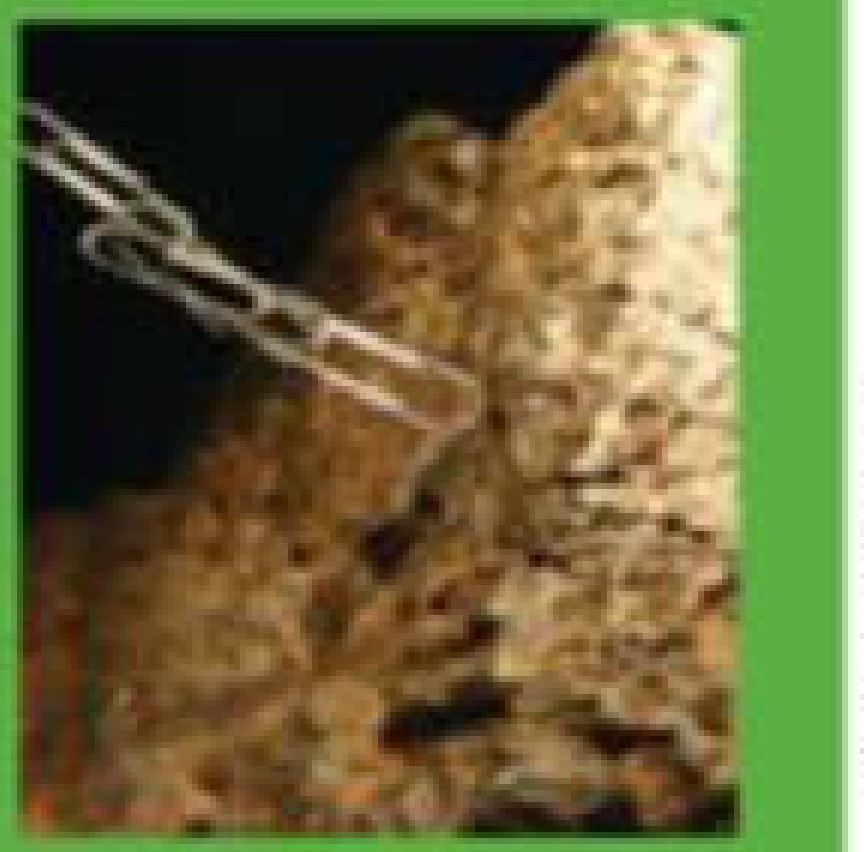
Ferromagnetism

The strongest magnet in this list, a ferromagnet retains magnetism unless heated to a temperature known as the Curie point. Cooling it again will return its ferromagnetic properties. Every atom in a ferromagnetic material aligns when a magnetic field is applied. Horseshoe magnets are ferromagnets.

© Gregory F. Maxwell

Ferrimagnetism

Ferrimagnets have a constant amount of magnetisation regardless of any applied magnetic field. Natural magnets like lodestones (magnetite) are ferrimagnets, containing iron and oxygen ions. Ferrimagnetism is caused by some of the atoms in a mineral aligning in parallel. It is different from ferromagnetism in that not every atom aligns.



© Ryan Somma

Antiferromagnetism

At low temps, the atoms in an antiferromagnet align in antiparallel. Applying a magnetic field to an antiferromagnet such as chromium will not magnetise it, as the atoms remain opposed. Heating to Néel temp (when paramagnetism can occur) will allow weak magnetism, but further heating will reverse this.

© Alchemist

Paramagnetism

Paramagnets, such as magnesium and lithium, have a weak attraction to a magnetic field but don't retain any magnetism after. It's caused by at least one unpaired electron in the atoms of a material.

Diamagnetism

Gold, silver and many other elements in the periodic table are diamagnets. Their magnetic loops around the atoms oppose applied fields, so they repel magnets. All materials have some magnetism, but only those with a form of positive magnetism can cancel the negative effects caused by diamagnetism.

© Jeff Belmonte

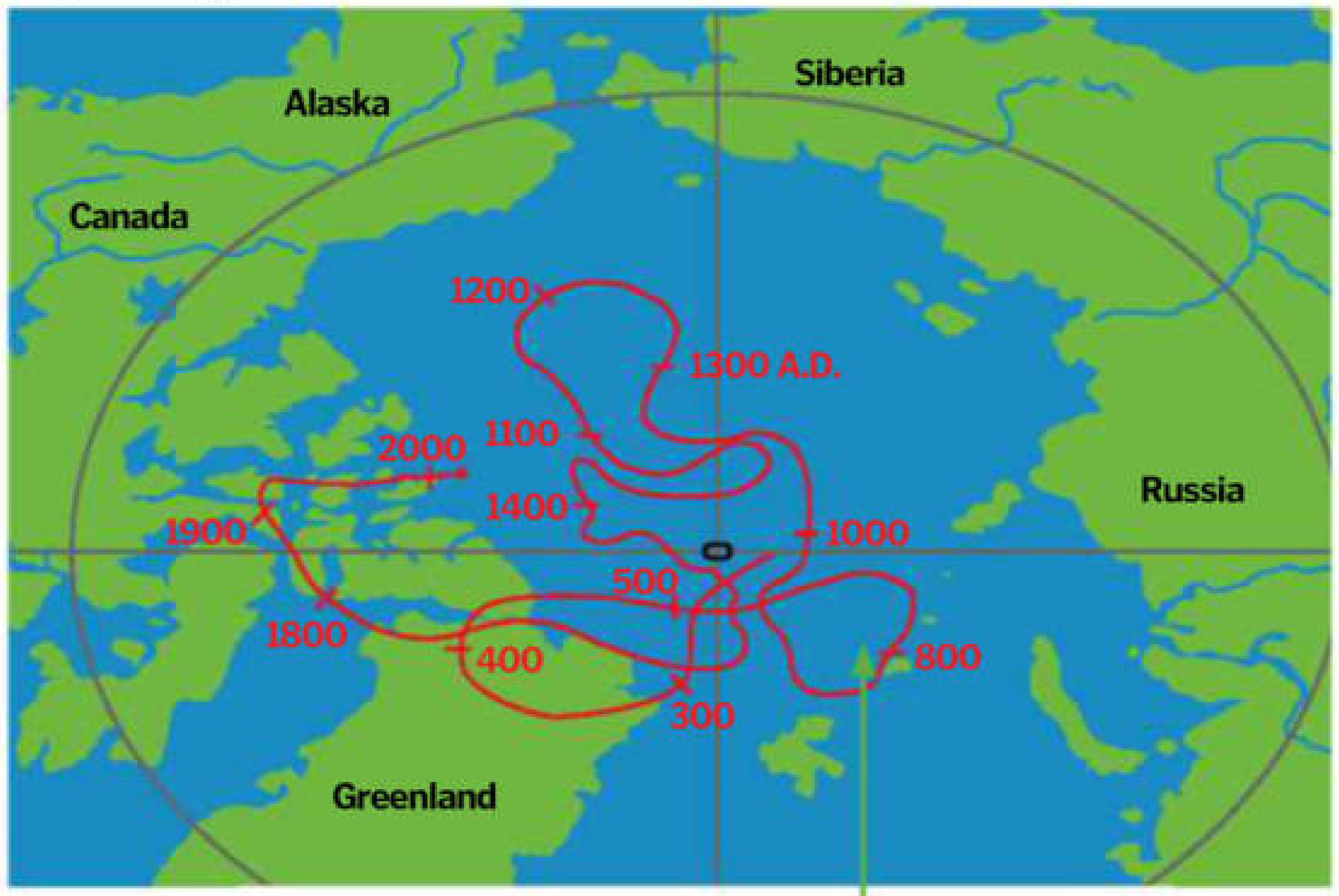
an iron atom, for example. Electrons circle the nucleus of an atom in cloud-like orbitals, commonly described as rigid shells (although in actuality, their motion is much more random). Each atom has a particular number of shells depending on how many protons and neutrons it has, while within each shell electrons orbit in pairs. Electrons are just like tiny magnets, each one having its own north and south pole. In their pairs, the electrons cancel out with one another so there is no overall magnetic force. In an atom such as that of iron, however, this is not the case. There are four electrons that are unpaired, which exert a magnetic force on the atom. When all the atoms are combined together and aligned, as we explained when talking about domains, the iron itself becomes magnetised and attracts other magnetic objects.

So we've snapped our magnet, broken it into chunks and subsequently examined the atoms of those tiny chunks. But is there a way that we can we go even deeper? The answer to that is yes and no, as we delve into the unknown areas of quantum physics. The underlying principle of magnetism is that in the universe there are four fundamental forces of nature; these consist of gravity, electromagnetism, the weak force and the strong force. Even smaller than atoms and electrons are fundamental particles known as quarks and leptons, which are responsible for these forces. Any force – such as gravity, magnetism, nuclear decay or friction – results from these fundamental life forces. A force such as magnetism at this level is 'thrown' between particles on what are known as force carrier particles, pushing or pulling the other particles around accordingly.

Unfortunately, at this level magnetism goes into the realm of theoretical physics, entering areas of quantum physics that have not been explored in as much detail as particle physics – at least for the time being. For now, this standard model of physics explains magnetism to a level that can only be furthered when we advance our understanding of quantum physics in the future.

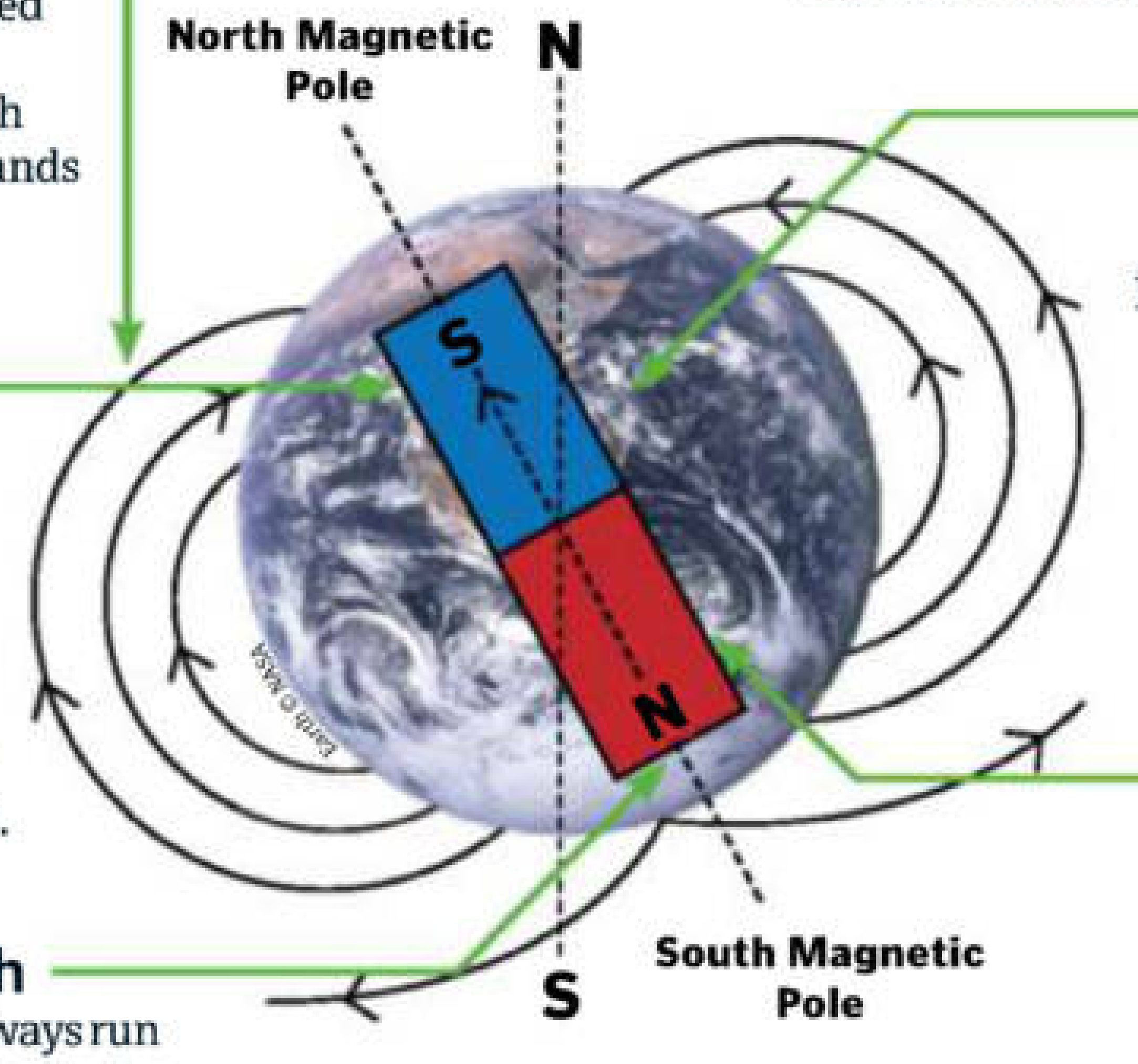
Earth's magnetic field

It's best to imagine the Earth as a bar magnet 12,400 miles (20,000km) long. The magnetic fields move around us like they would in a fridge magnet, but they also protect us from the universe. Compass needles always point to a magnet's south pole, so the Earth's geographical north pole is actually magnetically south.



Key: ⟶ wandering path of the magnetic north
⬬ rotational north pole

Magnetic movement
The North Magnetic Pole moves up to 1mm a second because of changes in the core. In 2005 it was pinpointed just off Ellesmere Island in Canada, but is now moving towards Russia.



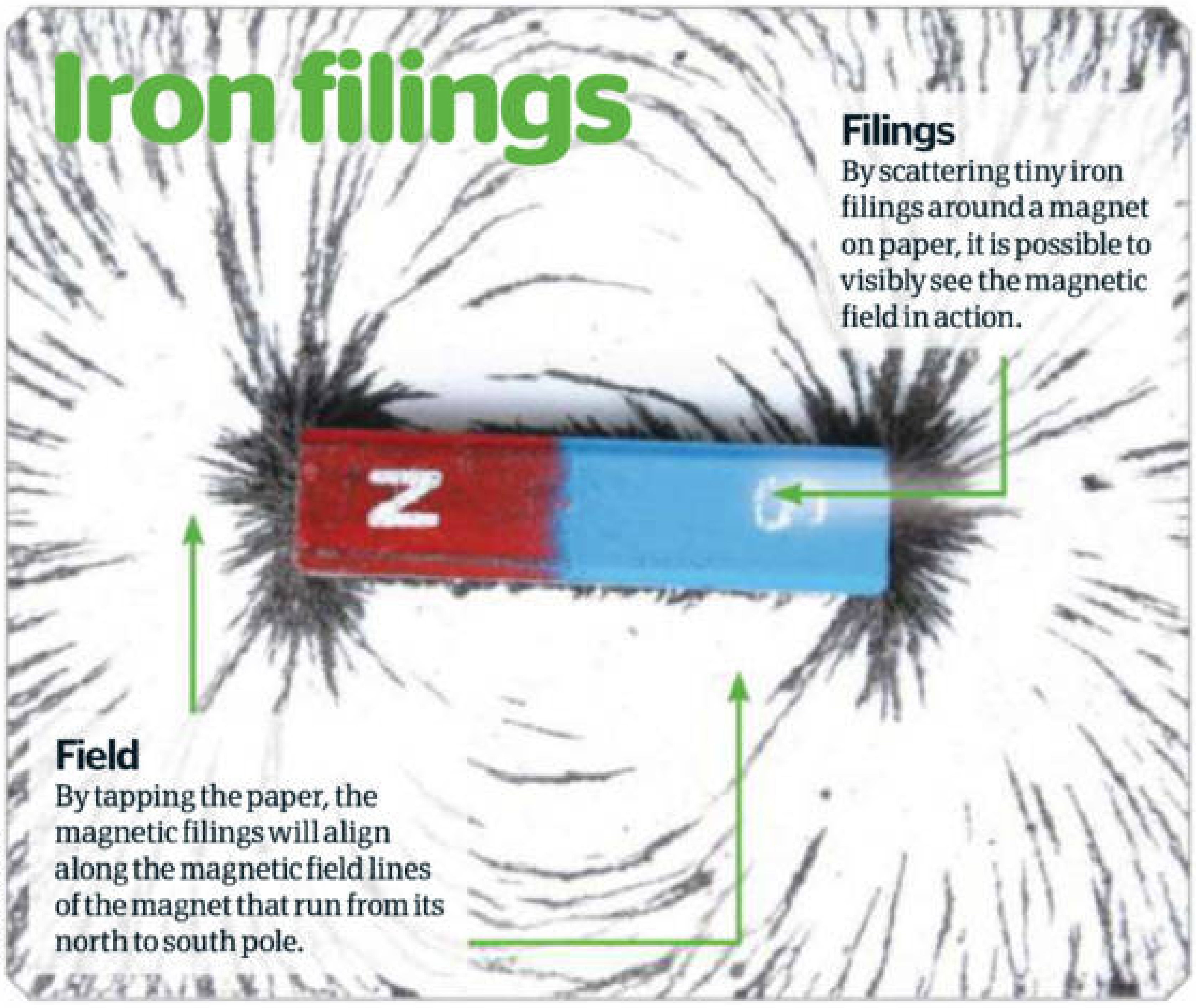
Effect
Charged particles from the Sun are deflected by the Earth's magnetic field, with some trapped in bands of radiation.

Tilt
The central 'bar magnet' of the Earth's magnetic field, the dipole, is tilted approximately 11° off the Earth's axis.

South is north
Magnetic fields always run from north to south, so when a compass points to the North Pole it is actually indicating southern magnetic polarity.

Cause
The magnetic field of any planet, including Earth, is the result of the circulation of electrically conducting material in the core, in our case molten iron.

Off-centred
The magnetic north and south poles do not draw a straight line through the centre of the Earth. In fact, they miss by several hundred miles.



Iron filings

Filings
By scattering tiny iron filings around a magnet on paper, it is possible to visibly see the magnetic field in action.

Field
By tapping the paper, the magnetic filings will align along the magnetic field lines of the magnet that run from its north to south pole.

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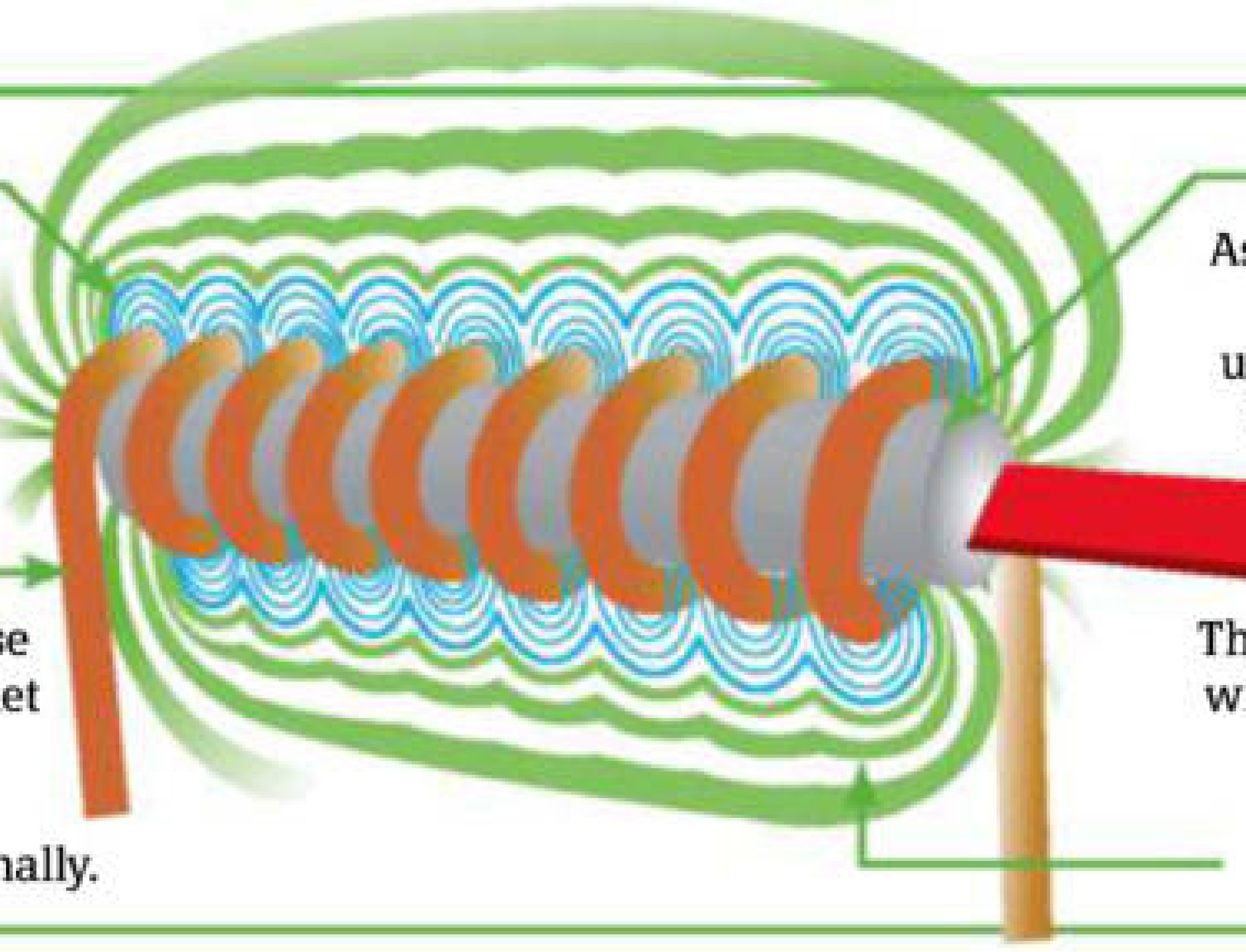
Electromagnets

One of the four fundamental forces in the universe, electromagnetism results from the interaction of electrically charged particles. Physicist Michael Faraday deduced that a changing magnetic field produces an electric field, while James Maxwell discovered that the reverse is also true: a changing electric field produces a magnetic field. This is the basis of how an electromagnet works.



Electric fields
A wire wrapped around a magnetic core, such as iron, produces electric fields when a current runs through it, in turn creating a magnetic field.

Coil
The number of coils will increase the strength of the electromagnet because there is more current flowing in one direction, magnifying the force proportionally.

Core
As discussed on the previous page, the domains within the core are unaligned until a magnetic field is introduced, created by a moving current in the coil.

Magnetic field
The wire's magnetic field combines with the field of the core to produce a stronger field, with a larger current aligning more domains and increasing its strength.

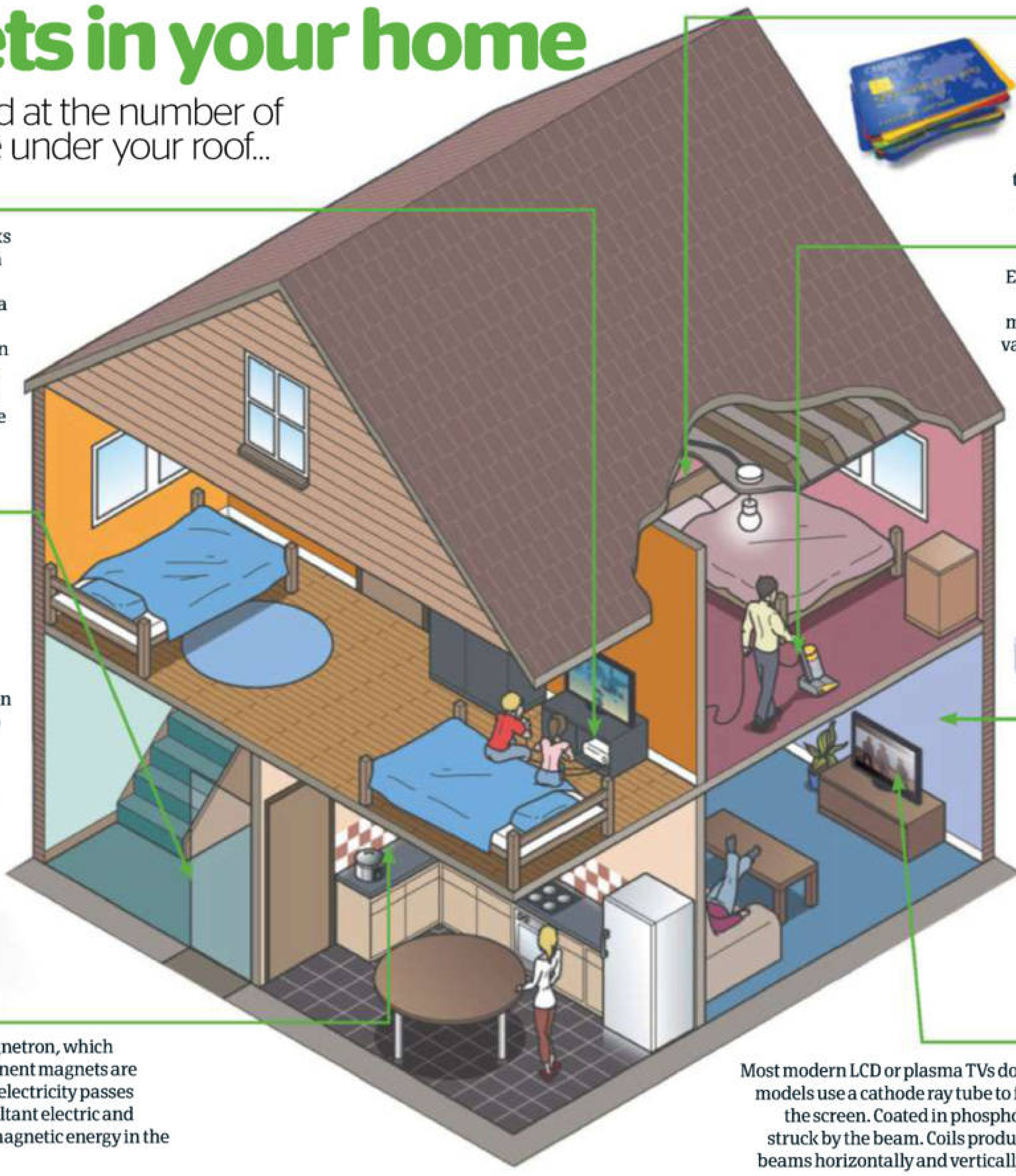
Magnets in your home

You'll be surprised at the number of magnets that are under your roof...

Computer
Like credit cards, the storage disks inside computers are coated with bits of iron. By changing the magnetic orientation of the iron, a pattern can be created to store a particular set of data. This pattern can be read by the computer and replicate the data on screen. The monitor itself uses magnets in the same way as an old cathode ray tube TV (see television).

Doorbell
For a buzzer-style doorbell, pressing the button moves and releases a contact from an electromagnet to break and complete a circuit. A chiming doorbell, meanwhile, moves an iron core through an electromagnet coil and back when the button is pressed, hitting two chime bars in sequence.

Microwave
Inside a microwave oven is a magnetron, which contains magnets. Strong permanent magnets are mounted inside this tube. When electricity passes through the magnetron, the resultant electric and magnetic fields produce electromagnetic energy in the form of microwaves.



Credit card
All credit cards have a black magnetic stripe. Inside, tiny bits of iron are held in a plastic film. These can be magnetised in a north or south direction to store data. When you swipe the card through a machine, information is read from the line of magnets.

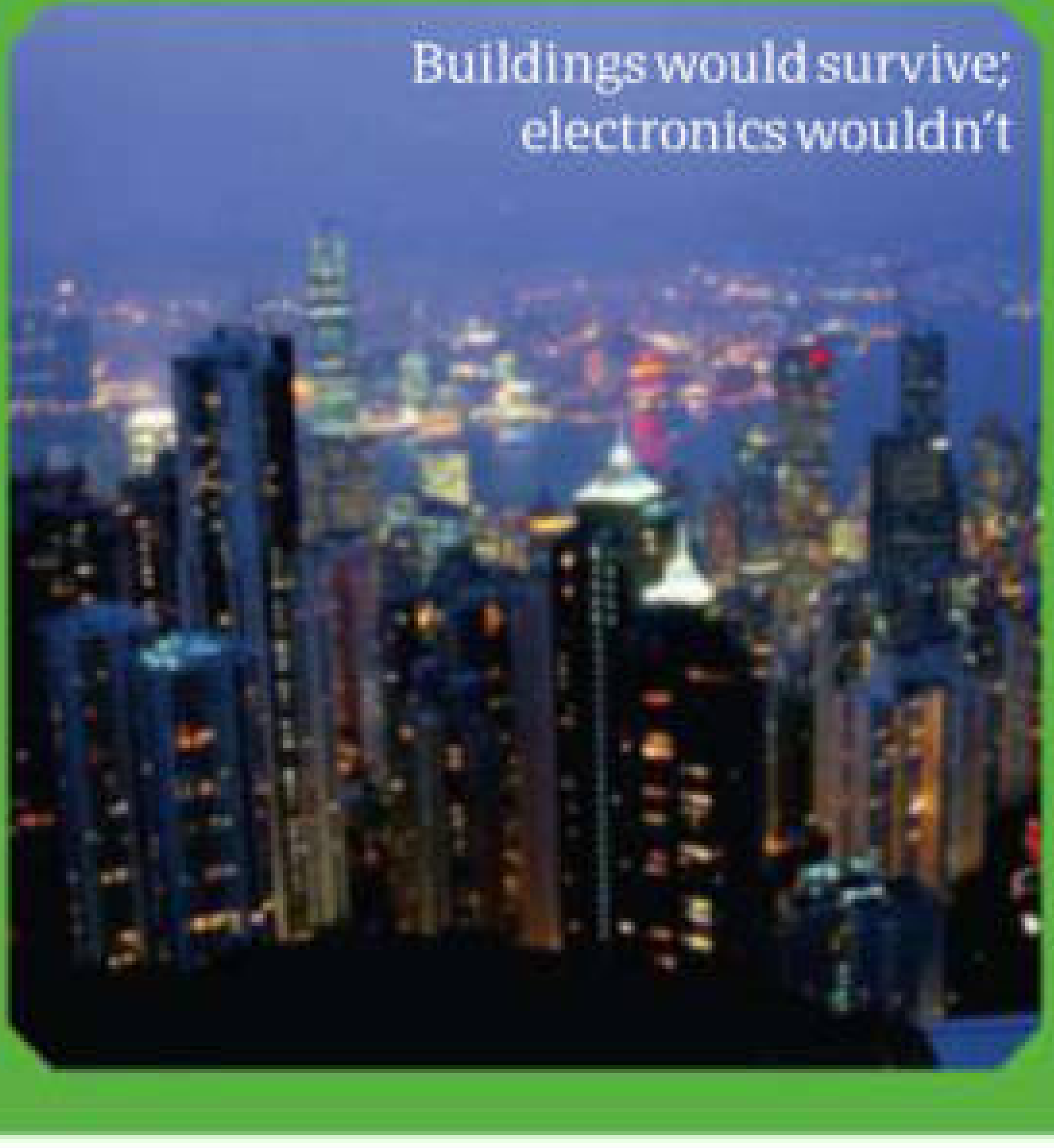
Vacuum cleaner
Electromagnetism is used here. A magnetically conducting material is inside the motor of the vacuum cleaner. When an electric current is introduced to a coil around the material, repulsive forces make the motor spin. The material loses its magnetism when the vacuum is turned off.

Speakers
Using electromagnetism, most speakers contain a stationary magnet and a wire coil inside a semi-rigid membrane. When a current runs through the coil, the membrane rotates in and out due to the force between coil and magnet, creating vibrations that produce sound. Phone speakers use this same mechanism, only smaller.

Television
Most modern LCD or plasma TVs don't use magnets. However, older models use a cathode ray tube to fire electrons against the back of the screen. Coated in phosphor, parts of the screen glow when struck by the beam. Coils produce magnetic fields that move the beams horizontally and vertically to produce the desired picture.

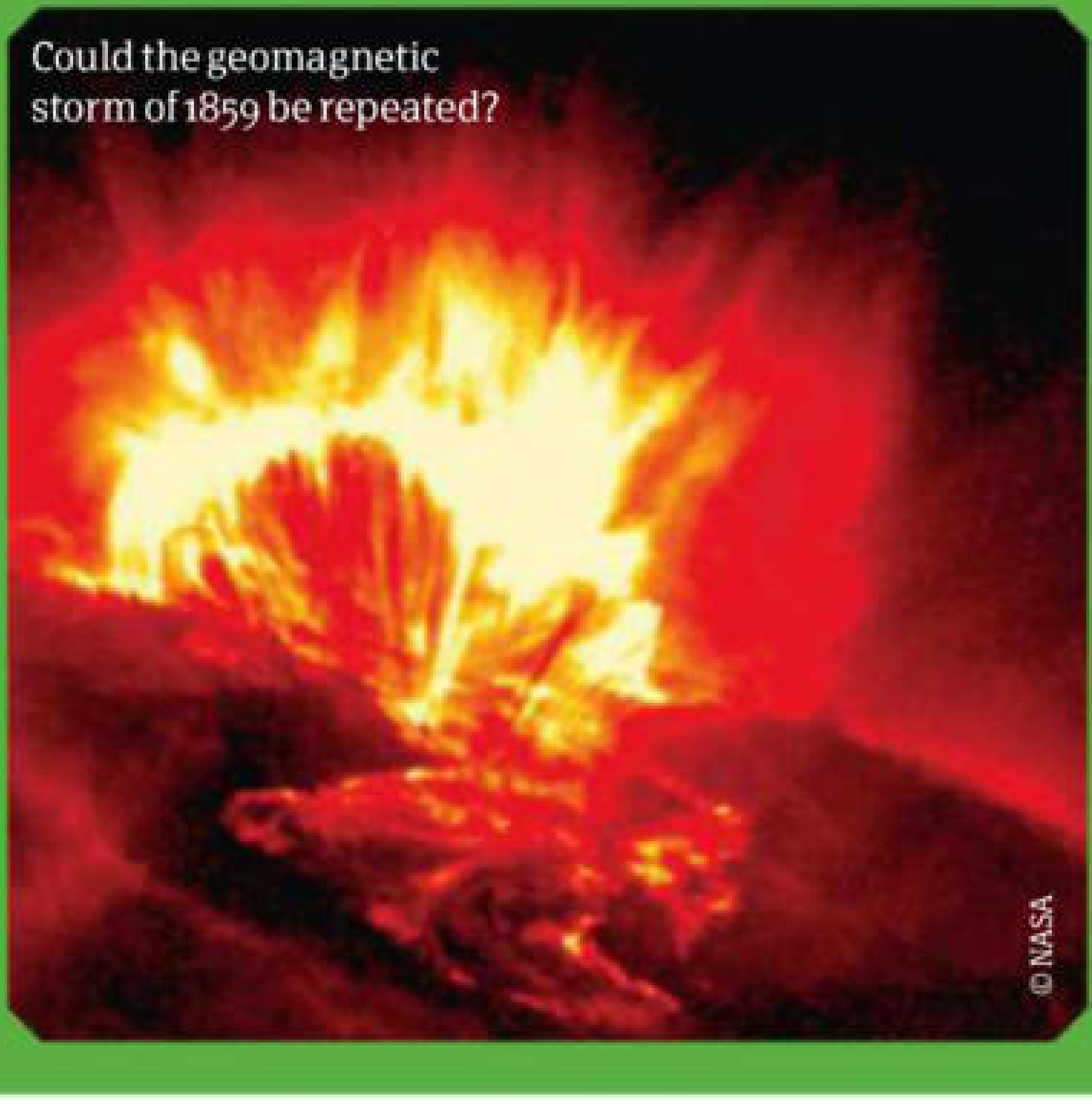
EMP

An Electromagnetic Pulse (EMP) works by overwhelming electric circuits with an intense electromagnetic field. A non-nuclear EMP explodes a metal cylinder full of explosives inside a coil of wire, pushing out magnetic and electric fields that fry electric circuits. A nuclear EMP would explode a nuclear bomb in the atmosphere. The resultant gamma radiation would take in positive air molecules but push out negative electrons, sending a large electromagnetic field in all directions. A 10-megaton device detonated 200 miles (320km) above the centre of the United States would destroy every electronic device in the country but leave the structures and life intact.



Buildings would survive; electronics wouldn't

Future solar blackout?



Could the geomagnetic storm of 1859 be repeated?

© NASA

In 1859, a great geomagnetic storm wiped out transmission cables and set fire to telegraph offices when the Sun went through a period of intense activity. The Sun's magnetic cycle peaks every 22 years, while every 11 years the number of solar flares hits a maximum. In the future these events could combine and produce huge levels of radiation, potentially wiping out power on many modern electrical components for hours – or even days on Earth.

What is blood? p60
What makes a human? p54
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The human

54 What are you made of?
Find out about the different materials that make up the human body

60 How your blood works
A look at the live-giving fluid

64 Human respiration
How we use lungs to breathe

66 A look inside your heart
An essential organ in humans, this little beater sets the pace of your life

67 How do allergies affect us?
Hay fever seems to be at an all-time high, so how does our body cope with allergy?

67 Suffering with asthma
Why this respiratory problem makes it hard to breathe

68 Kidney function
Filtering waste to keep you healthy, kidneys are very hard workers

70 How the liver works
The ultimate multitasker, this amazing organ is your body's power generator

72 The human hand
A crucial structure we take for granted

74 How do your feet work?
Keeping you on your toes

76 The human skeleton
Holding your body together is a tough scaffolding of bones

78 Muscle power
Getting your body moving is all about push and pull

82 What's inside your head?
Essential elements that help you think

84 What are moles?
These small skin blemishes are worth keeping an eye on

84 Why do we get spots?
What causes those pimples on our skin

What do your kidneys do? p68

How does the human brain work? p82

What makes a skeleton? p76

What is muscle? p78

What's inside hands? p72

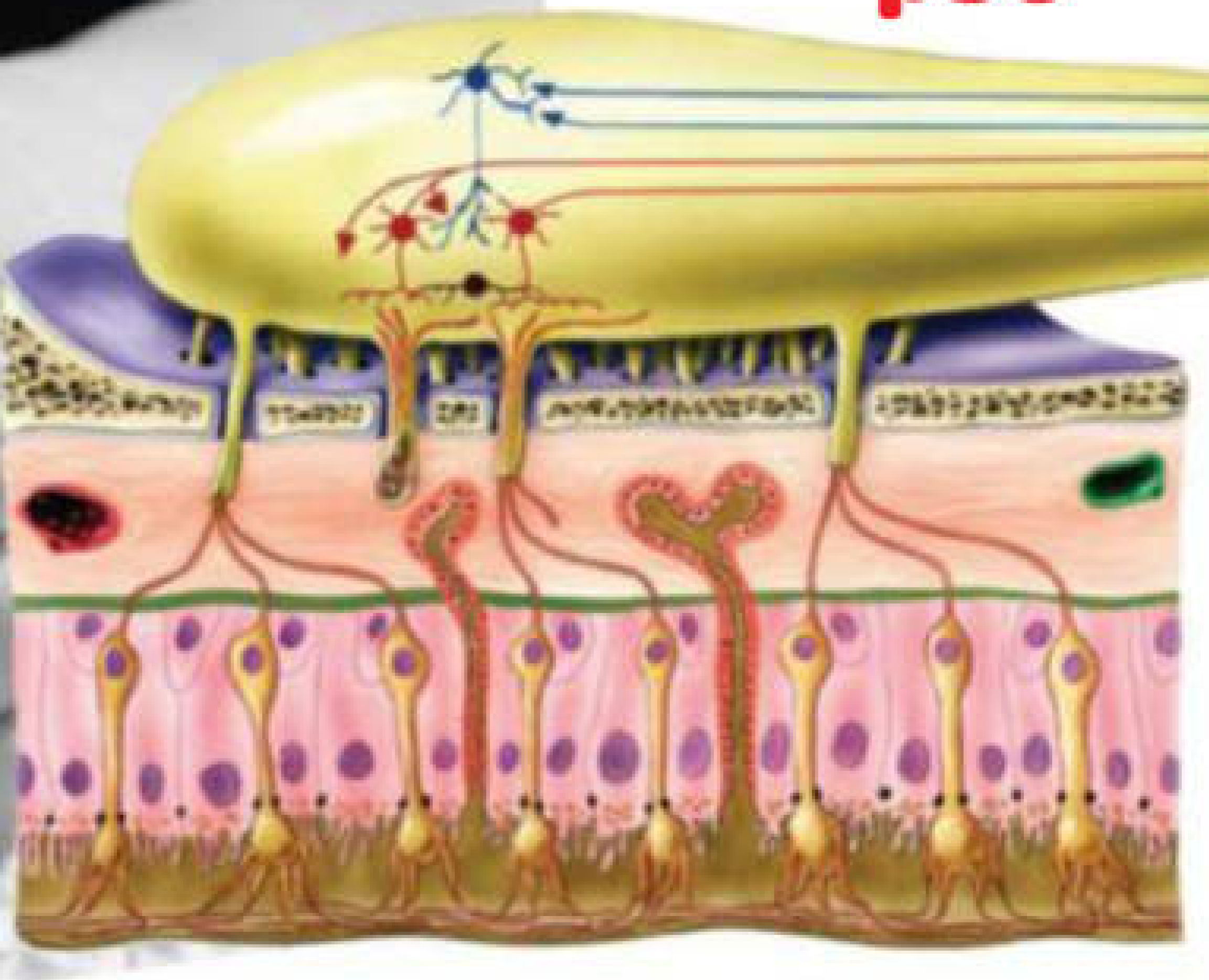
body

85 What are tonsils for?
Just why do we have those fleshy lumps at the back of our throats?

86 The sensory system
Our senses help us to experience the world around us

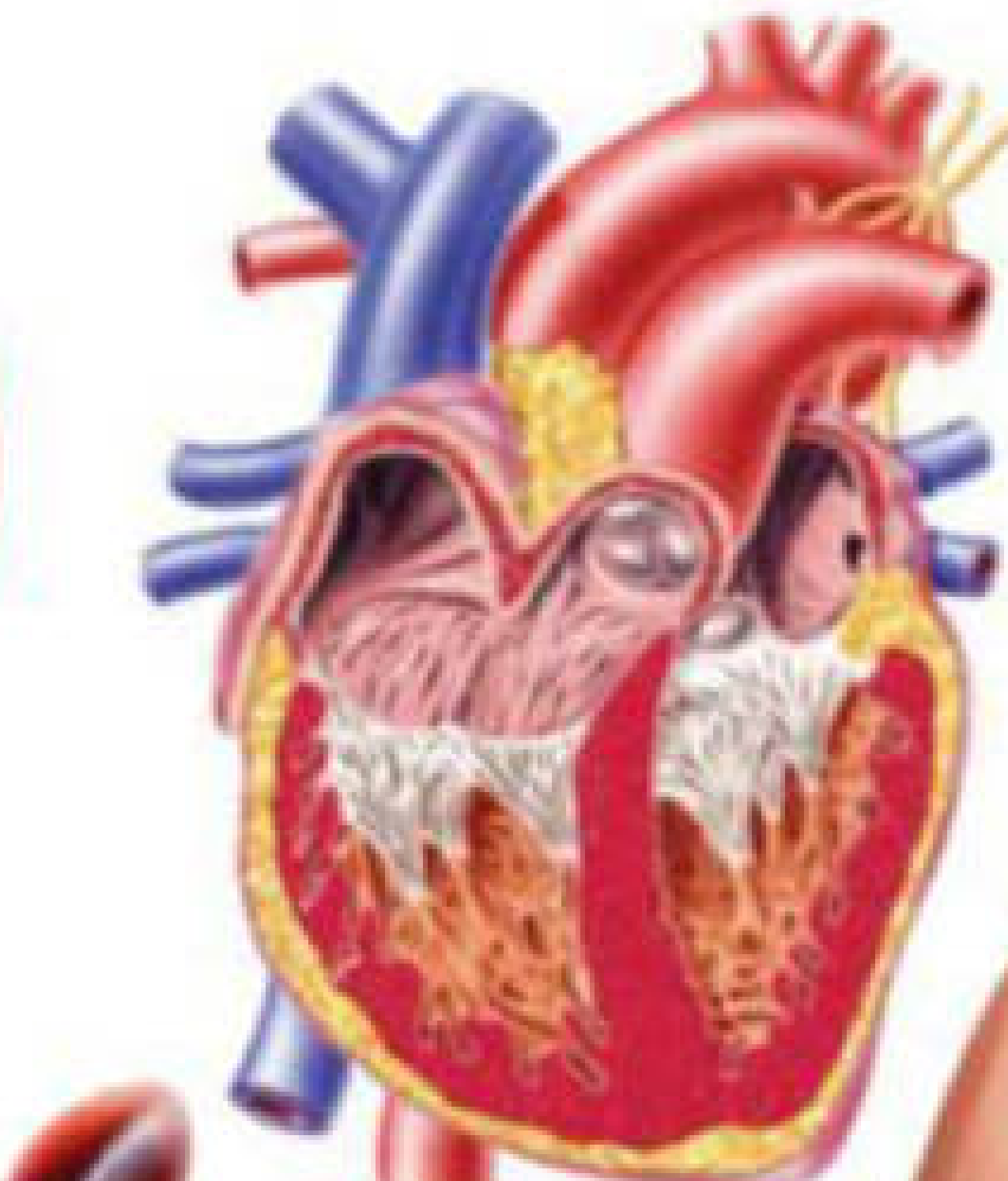
How do feet work? p74

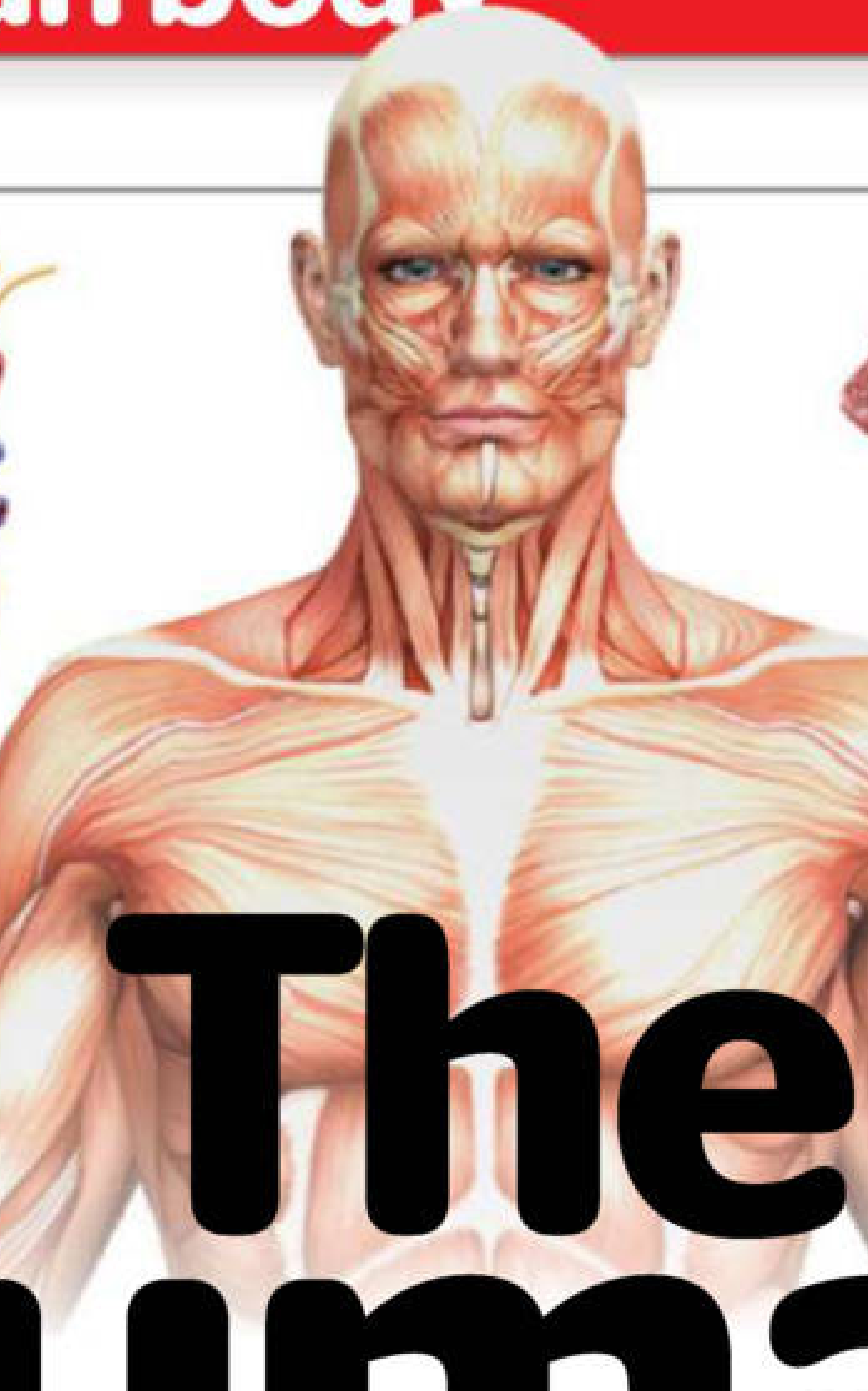
How do we smell? p86



The human body

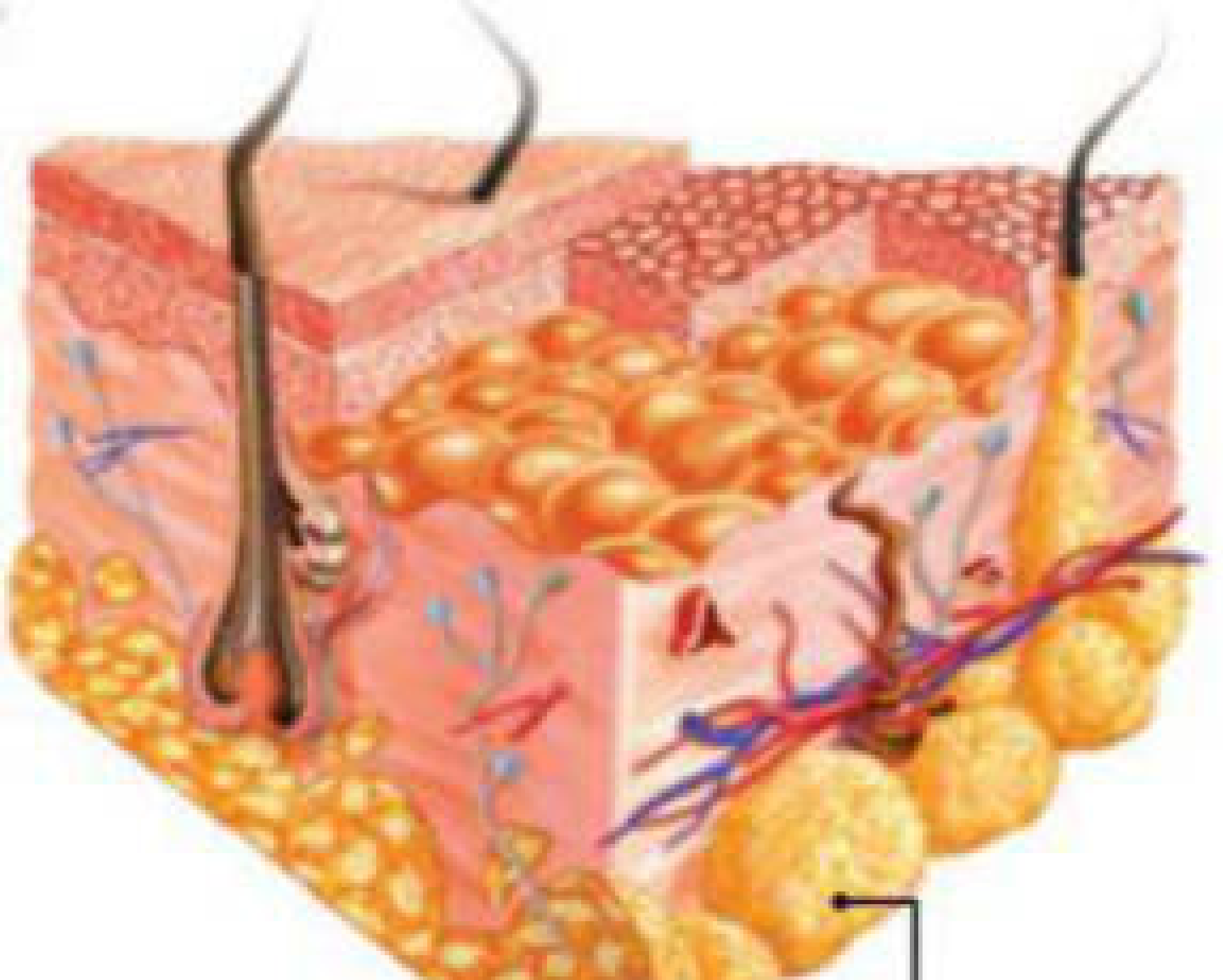
Journey inside the body to discover just what we are made of...



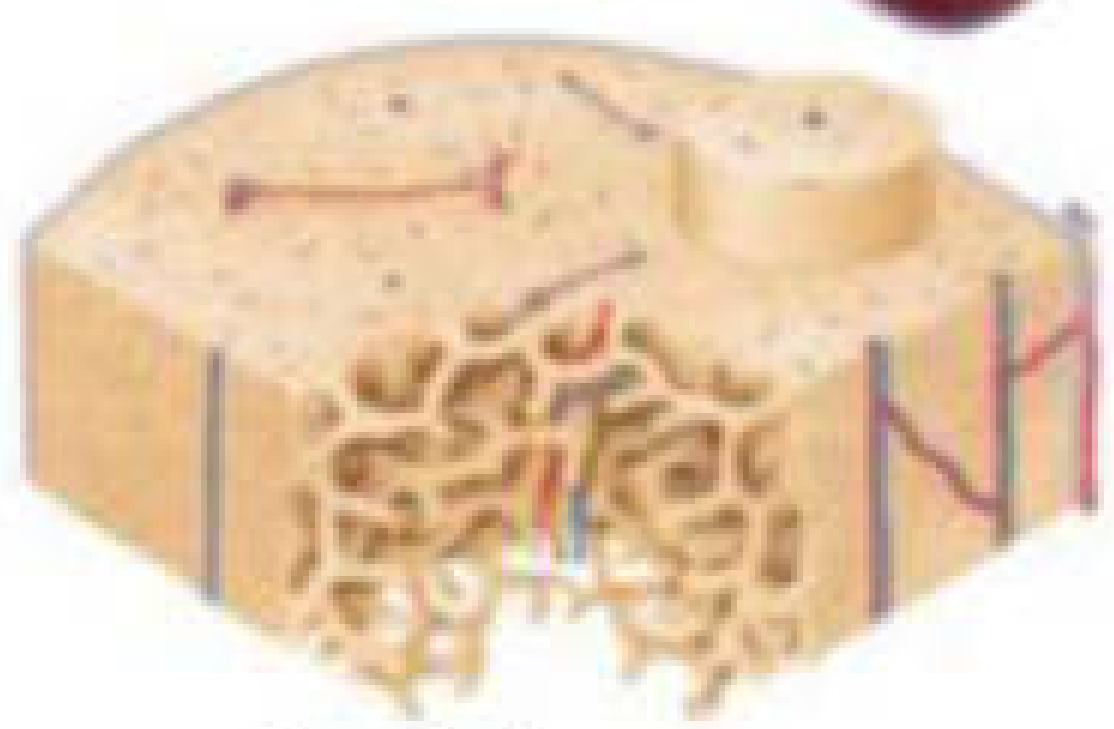


The male cerebral cortex has about 23 billion neurons

Red blood cells can live for up to 120 days



$1cm^2$ of skin can contain 70cm of blood vessels



The body comprises around 75 trillion cells

99% of the body is made of just 6 elements

Making connections
The hyoid in the neck is the only bone that isn't connected to another bone

The human body is composed of an estimated 7 octillion (which written out is 7,000,000,000,000,000,000,000,000,000) atoms, making up over 75 trillion cells.

At the atomic level, the human body comprises about 60 elements, but the function of many of them is unknown. In fact, 99 per cent of the human body is made from just six elements (see chart for specific percentages).

Like all other life discovered to date, we are carbon-based; the biomolecules that make up our bodies are constructed using frameworks made up of carbon atoms. Carbon is almost unique among the elements; it is small in size and can make four covalent bonds to other atoms, allowing it to form the backbone of some of the key molecules that form the human body, including proteins, fats, sugars and DNA. The bonds are strong enough to hold the molecules in a stable structure, but not so strong that they cannot be taken apart again, allowing the body to break and reform molecules over and over again as it requires.

Calcium is the most abundant mineral in the human body, and it plays the important role of regulating protein production and activity.

Complex cascades of chemical reactions occur within the gel-like cytoplasm and organelles of cells – tiny structures that perform specific functions within a cell. Phosphorus is used to make adenosine triphosphate (ATP), which has high-energy phosphate bonds that can be broken in order to power cellular processes; ATP is essentially our cells' fuel.

Cells are coated in receptors and respond rapidly to environmental changes, communicating via chemical signals and electrical impulses. During embryonic development, chemical gradients tell developing cells where to go, and what cell type to become, resulting in a new person.

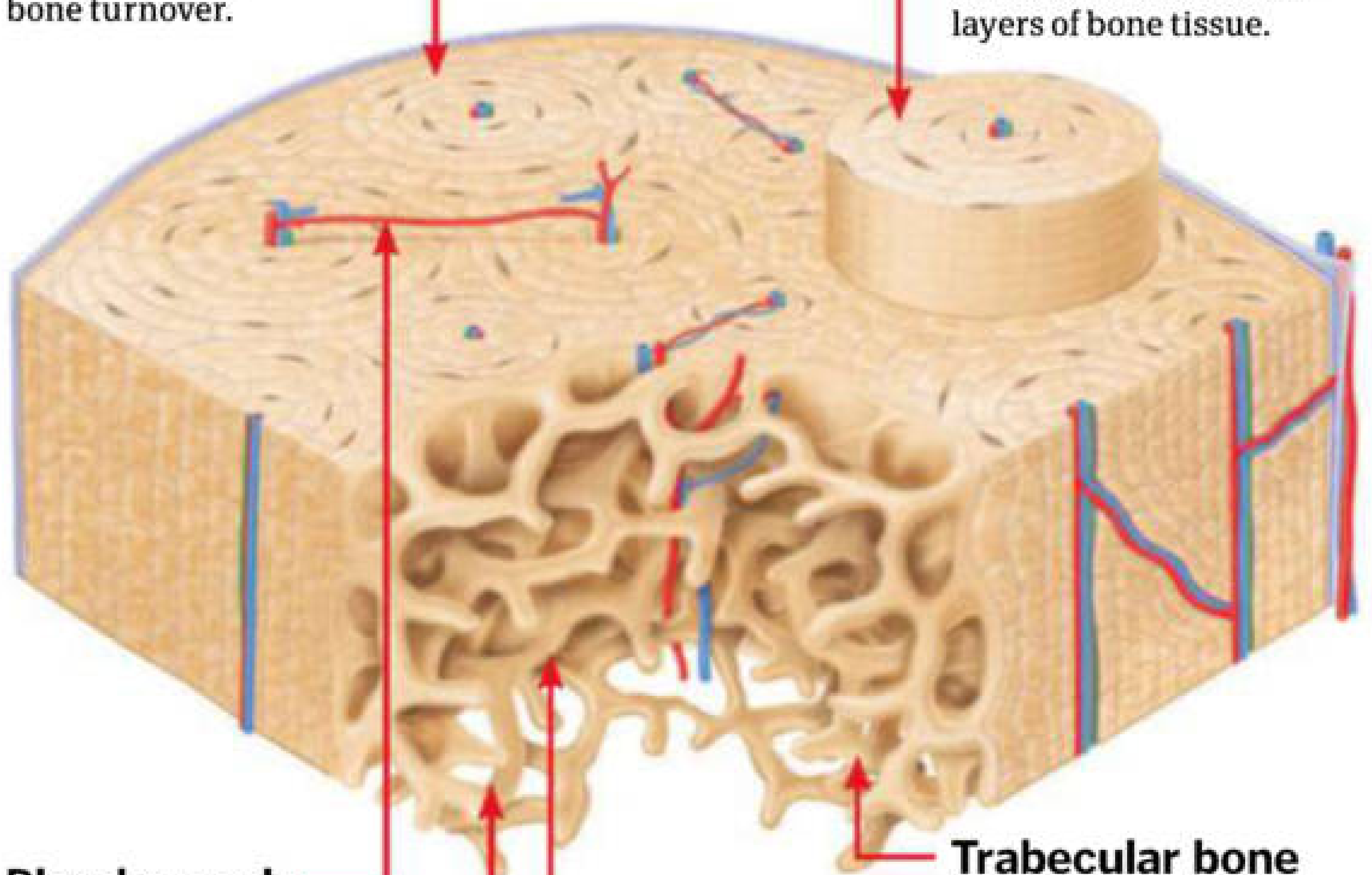
Interestingly, the majority of the cells in the human body are not human. Microbes make up between one and three per cent of our body mass and are important for helping us function. They have 8 million different coding genes for making proteins, compared to less than 30,000 in the human genome.

The bacteria living in our digestive system provide essential support too; they ferment undigested carbohydrates, allowing us to access energy we couldn't otherwise, and they have a role in the production of vitamins like biotin and vitamin K. They also prevent 'bad' bacteria from taking hold in the gut and making us unwell. Even more unusually, at least eight per cent of the human genome is viral in origin. Retroviruses are able to insert DNA into our chromosomes, and at several points in evolution genes that started out in viruses have joined with our genetic information.

How many hairs?
A human head has an average of 100,000 to 150,000 hairs

The structure of bones

The long bones of the body, such as the femur (thighbone), contain two distinct types of bone



Osteocyte
The cells that form the bone matrix eventually become trapped in it. They help to regulate bone turnover.

Cortical bone
The tough outer layer of bones contains densely packed cylindrical structures – osteons – formed from concentric layers of bone tissue.

Blood vessels
Bone is a metabolically active tissue and a good blood supply allows for mineral exchange.

Trabecular bone
Within the ends of long bones is a looser, honeycomb structure, where calcium is released from storage as required.

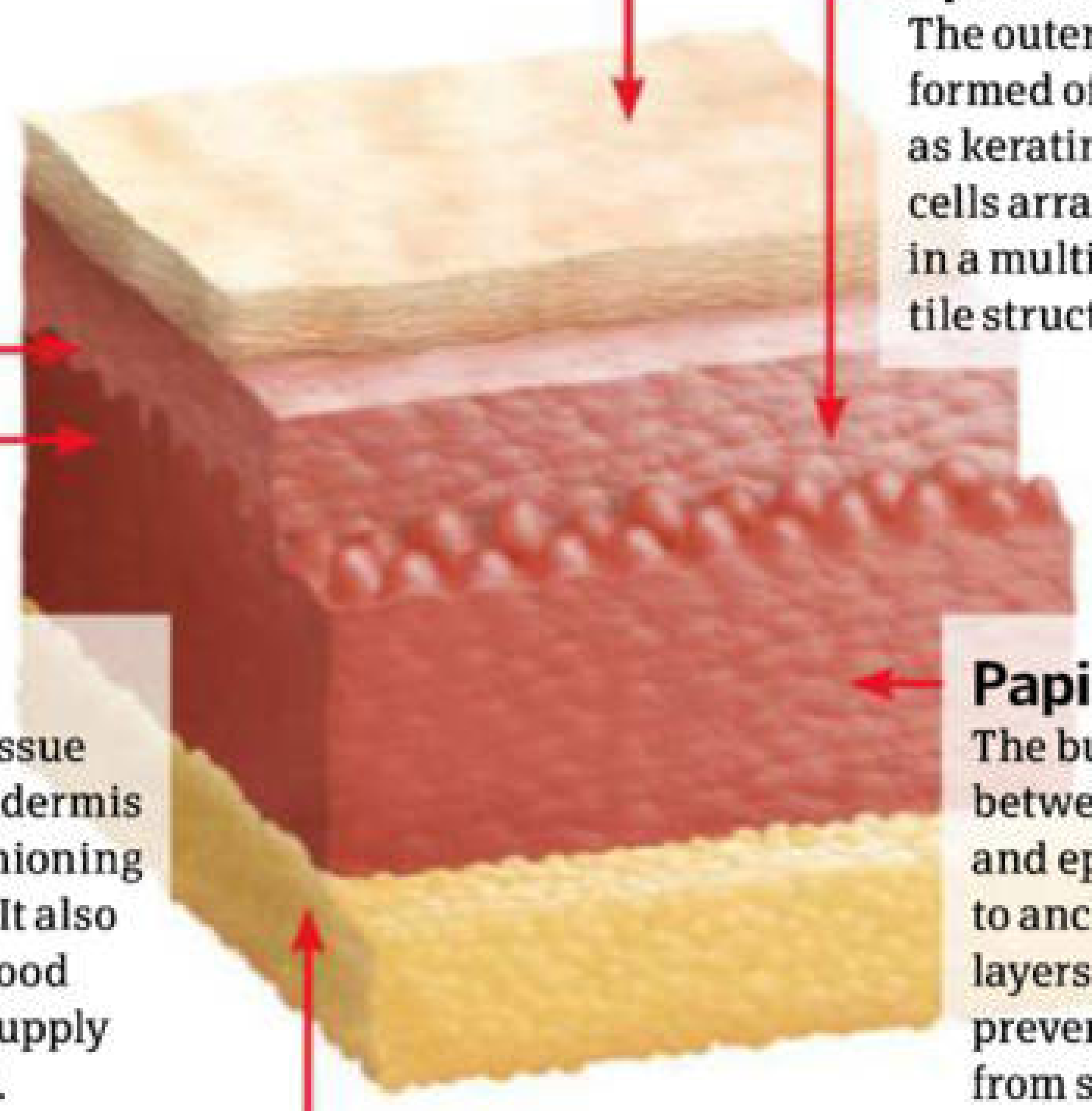
Osteoblast
Osteoblasts make new bone, producing the collagen scaffold and laying down minerals.

Osteoclast
Osteoclasts are related to cells of the immune system and digest old bone to release minerals and allow for remodelling.

Beneath the skin

Skin has several layers with a unique function

Largest organ of the body
The skin of a human adult measures two square metres (22 square feet)



Stem cells
A layer of stem cells at the base of the epidermis divides to form new skin cells, which push upwards to replace the dead ones.

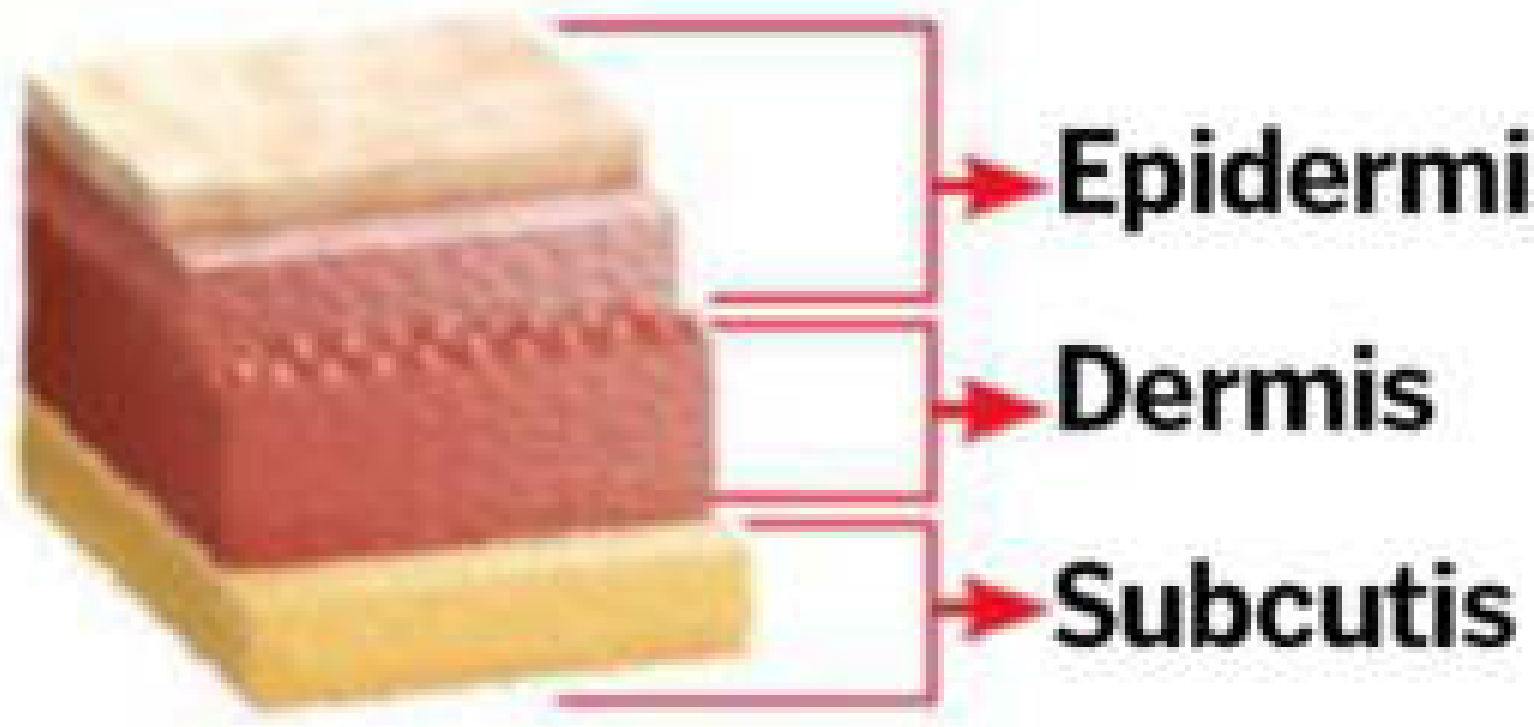
Cornified layer
The very outer layer of the skin consists entirely of flattened, dead cells. These provide a protective barrier.

Epidermis
The outer layer of skin is formed of cells known as keratinocytes. These cells arrange in a multilayered tile structure.

Dermis
Connective tissue below the epidermis provides cushioning and support. It also carries the blood vessels that supply the skin cells.

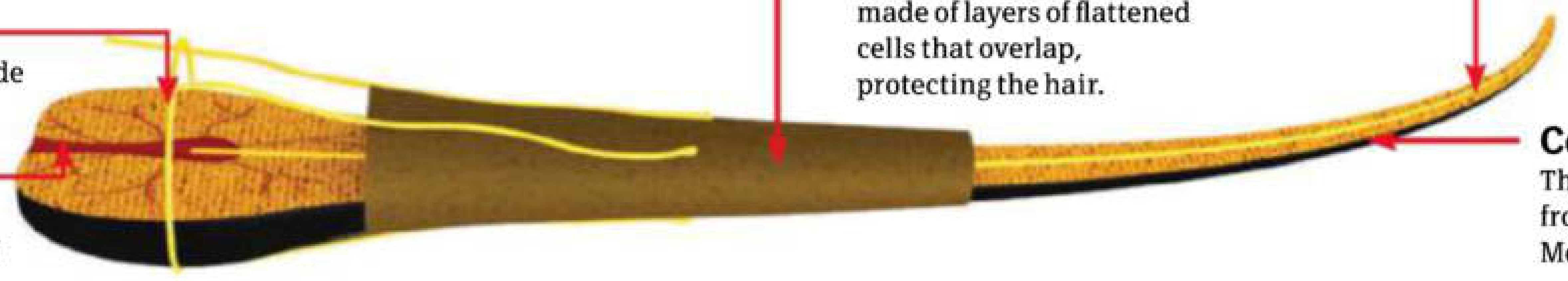
Papillae
The bumpy structure between the dermis and epidermis helps to anchor the two layers together, preventing them from slipping.

Fat
A layer of subcutaneous adipose tissue provides cushioning and insulation, as well as energy storage.



Hair under the microscope

A strand of hair can be divided into three distinct regions



Matrix
Cells of the matrix divide to produce new hair.

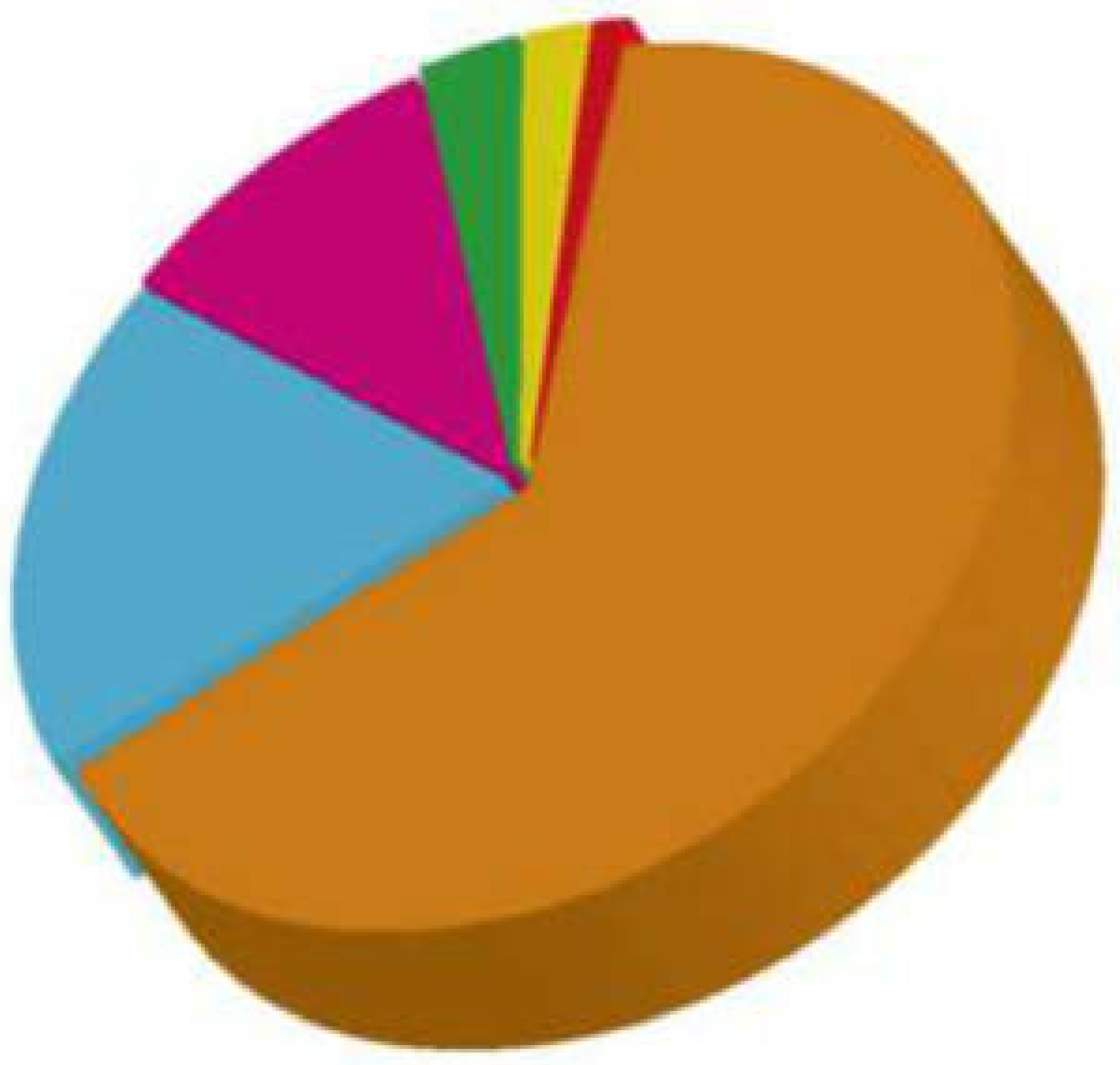
Papillae
Blood vessels supply nutrients to the cells of the matrix and root.

Cuticle
The outside of the hair is made of layers of flattened cells that overlap, protecting the hair.

Medulla
An open, unstructured core in the centre of the hair.

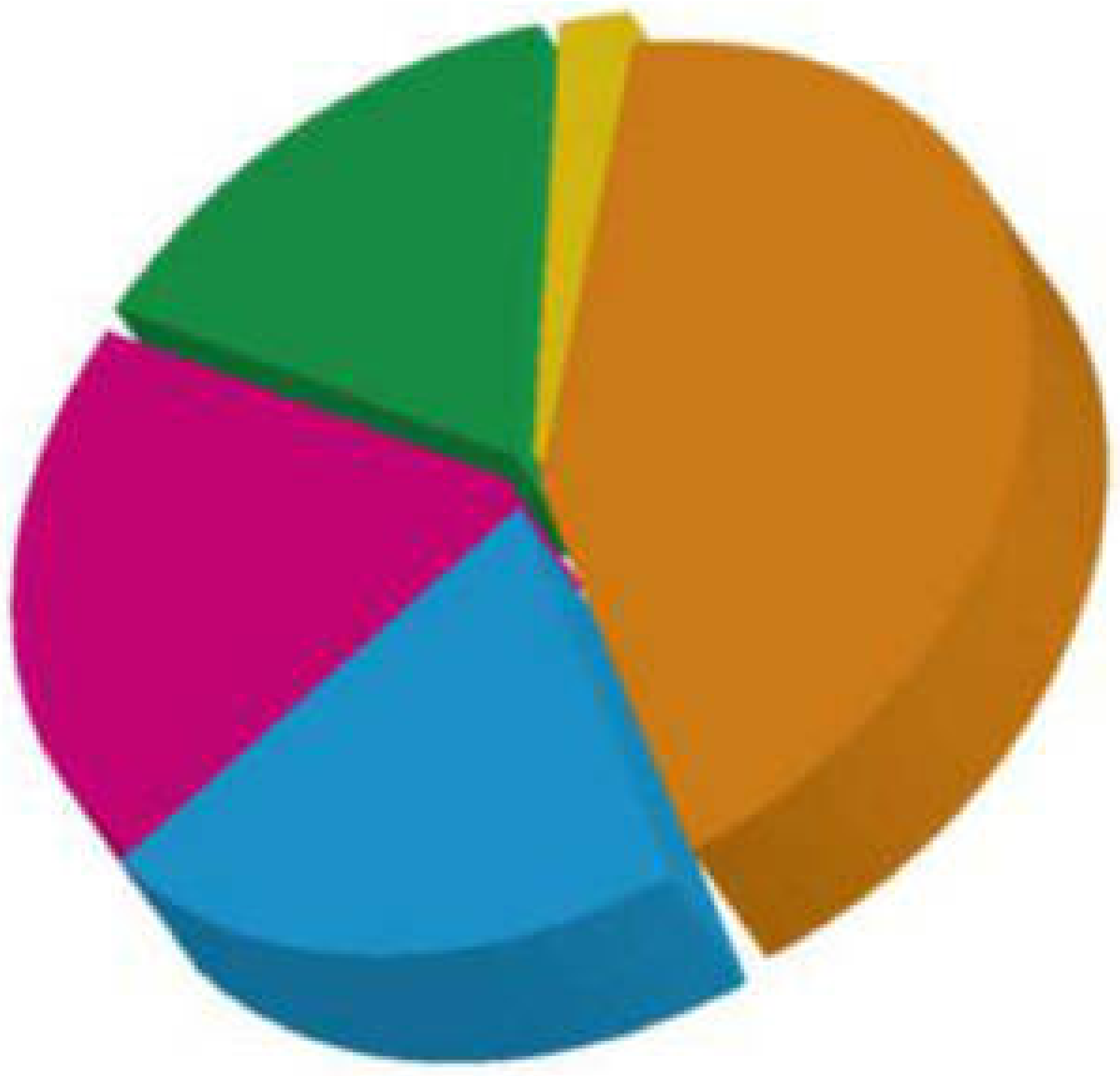
Cortex
The body of the hair is made from coiled strands of keratin. Melanin granules within the cortex lend it its colour.

Six main elements of the body (99%)



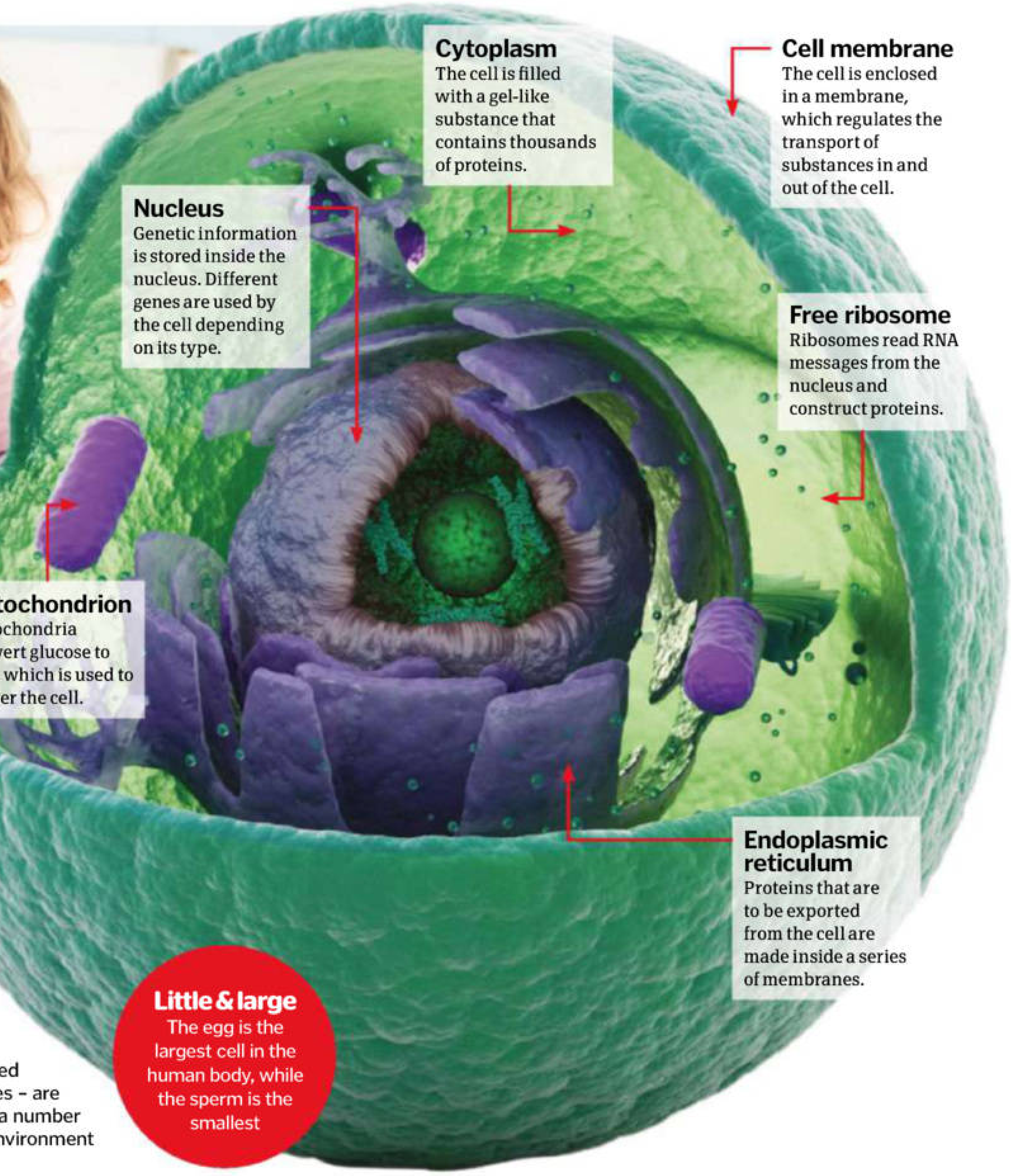
▶ **Oxygen:** 65%
▶ **Carbon:** 18%
▶ **Hydrogen:** 10%
▶ **Nitrogen:** 3%
▶ **Calcium:** 2%
▶ **Phosphorus:** 1%

Body composition by tissue type



▶ **Skeletal muscle:** 36-42%
▶ **Fat:** 13-20%
▶ **Bone:** 12-20%
▶ **Skin:** 16%
▶ **Brain:** 2%

The nucleus stores all sorts of genetic information



Cytoplasm
The cell is filled with a gel-like substance that contains thousands of proteins.

Cell membrane
The cell is enclosed in a membrane, which regulates the transport of substances in and out of the cell.

Nucleus
Genetic information is stored inside the nucleus. Different genes are used by the cell depending on its type.

Free ribosome
Ribosomes read RNA messages from the nucleus and construct proteins.

Mitochondrion
Mitochondria convert glucose to ATP, which is used to power the cell.

Endoplasmic reticulum
Proteins that are to be exported from the cell are made inside a series of membranes.

Close up with cells

There are thought to be over 200 different types of cell in the human body, each specialised to perform a particular function. Despite these specialisms, their basic underlying biology is the same.

Cells contain a nucleus, which houses the 46 chromosomes, containing the complete set of instructions to synthesise all of the proteins found in the human body. Depending on the type of cell, different genes are switched on and off, determining which proteins the cell will produce.

Proteins for use inside the cell are created on ribosomes in the cytoplasm. The ribosomes read the genetic message and assemble the corresponding protein using amino acids as building blocks. Proteins to be exported from the cell – for example, antibodies or digestive enzymes – are constructed within a series of membranes. Here they gain a number of modifications which enable them to survive the harsh environment when they leave the cell to travel around the body.

Little & large
The egg is the largest cell in the human body, while the sperm is the smallest

Key cells of the body

Blood and immune cells

Type: Blood

The cells of the blood, including red blood cells and the white blood cells of the immune system are all produced in the bone marrow. Red blood cells lack a nucleus, enabling them to pack more of the oxygen-carrying protein, haemoglobin, into their cytoplasm.

Epithelial cells

Type: Skin and membranes

The cells that cover our bodies and line our body cavities form junctions with one another. Using proteins anchored between their membranes, the cells join forces to create strong barriers to protect the body.

Contractile cells

Type: Muscle

These cells contain a protein ratchet system, which enables them to contract. Actin and myosin form long strands, which slide past one another, pulling the edges of the cell together.

Nerve cells

Type: Brain and nerves

Nerve cells have specialised membranes, which use molecular pumps to maintain an electrochemical gradient; this allows them to transmit electrical signals. Nerves function more efficiently if they are insulated and many nerve cells are covered by a fatty sheath of myelin.

Stem cells

Type: Undifferentiated

Stem cells are ones that have not yet committed to a particular specialism. They are found in many locations and provide a replicating reservoir of cells that can be used to maintain and repair the body.

Extracellular matrix cells

Type: Connective tissue

The cells of the body are supported by networks of fibres including collagen and elastin. These are generated by extracellular matrix cells like fibroblasts, which produce and secrete precursor components that then assemble into the fibres that make up the matrix.

Endocrine cells

Type: Hormones

These cells generate hormones and release them locally or into the bloodstream. Their hormone-releasing activity is controlled by neurotransmitters sent from local nerves, or by other chemical messengers, which bind to receptors that are on the cell surface.

Germ cell

Type: Reproductive

Sperm and egg cells have just one copy of each chromosome and are formed by a special type of cell division called meiosis. When sperm and egg combine, the resulting cell has a full set of 46 chromosomes.

Muscle and movement

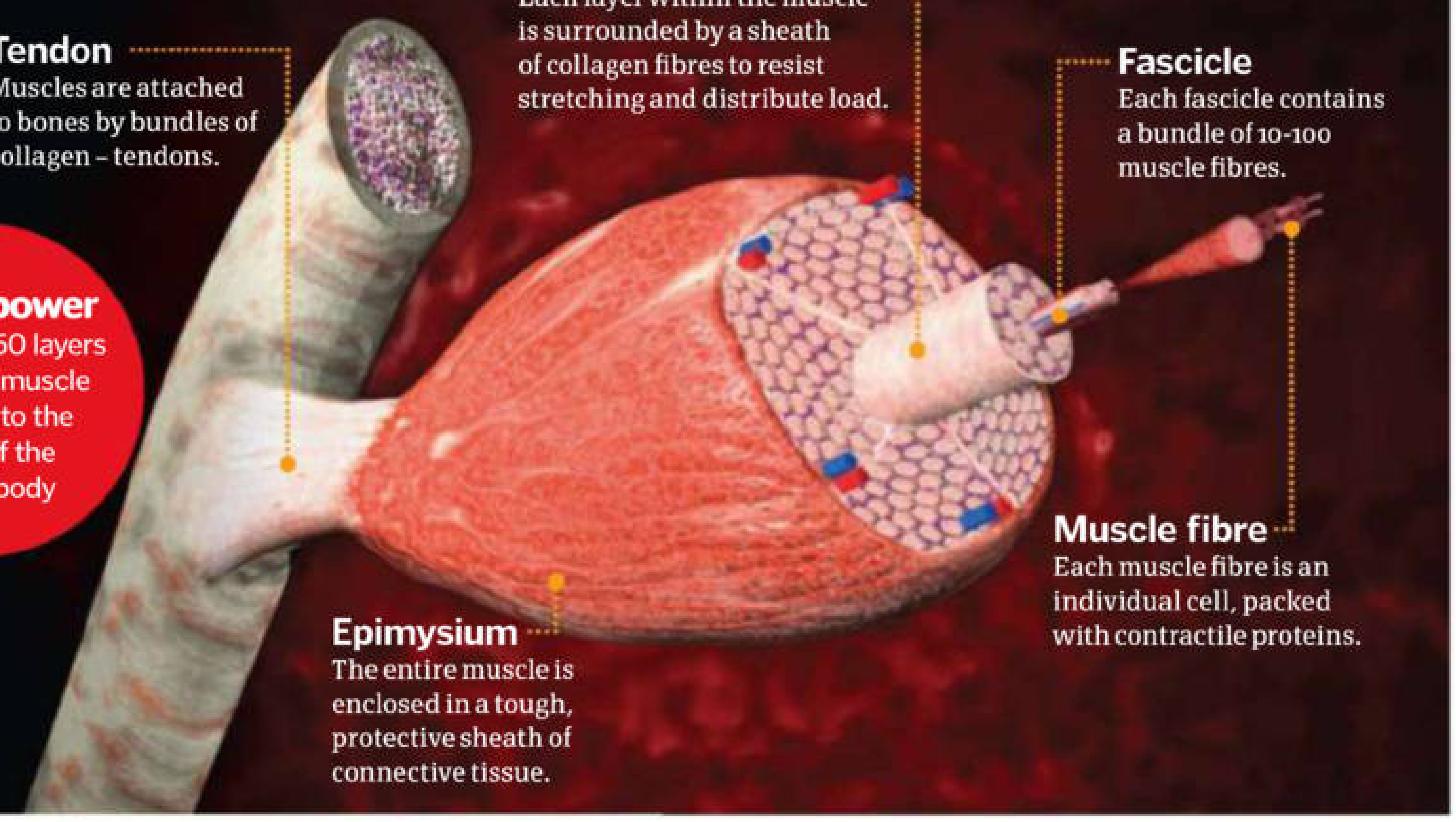
Skeletal muscle is responsible for moving the skeleton. It is composed of bundles of muscle fibres, sheathed in a strong collagen matrix, which extends into tendons that attach to the bone.

Within each muscle fibre is a molecular ratchet system made from the proteins actin and myosin. As the protein filaments slide past one another, the muscle fibre contracts lengthways and the fibre shortens.

Muscle fibres can be broadly categorised as being either 'fast twitch' or 'slow twitch'. Fast-twitch fibres use high-speed anaerobic respiration to produce rapid movements, but fatigue quickly. In contrast, slow-twitch fibres use sustainable aerobic respiration and produce slower movement for longer periods of time.

The proportion of slow and fast-twitch fibres affects athletic performance, eg long-distance runners have a higher proportion of slow-twitch fibres than sprinters. Whether muscle fibres can change from one to another is under investigation.

Muscle power
There are 650 layers of striated muscle attached to the bones of the human body



Tendon
Muscles are attached to bones by bundles of collagen – tendons.

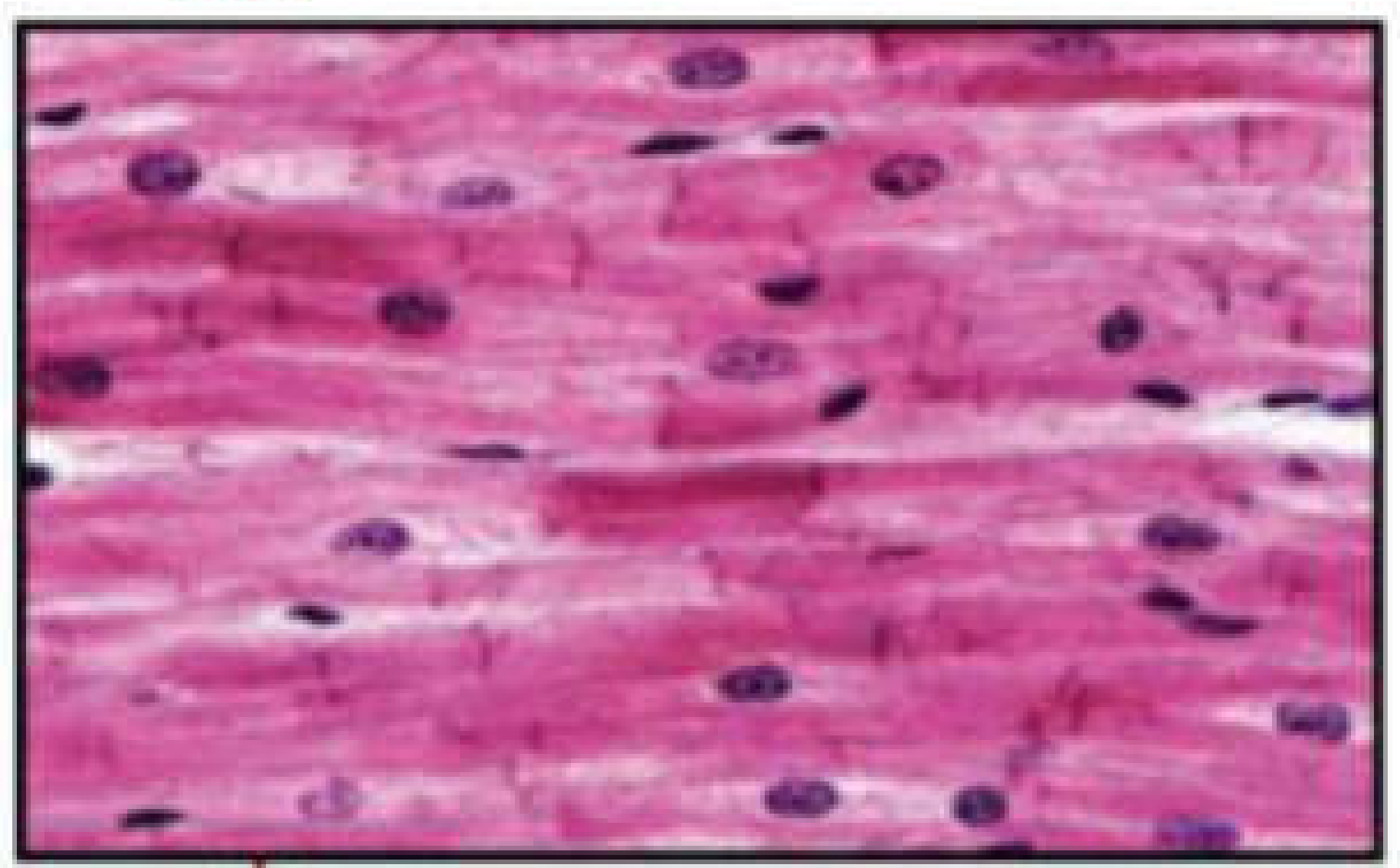
Connective tissue
Each layer within the muscle is surrounded by a sheath of collagen fibres to resist stretching and distribute load.

Fascicle
Each fascicle contains a bundle of 10-100 muscle fibres.

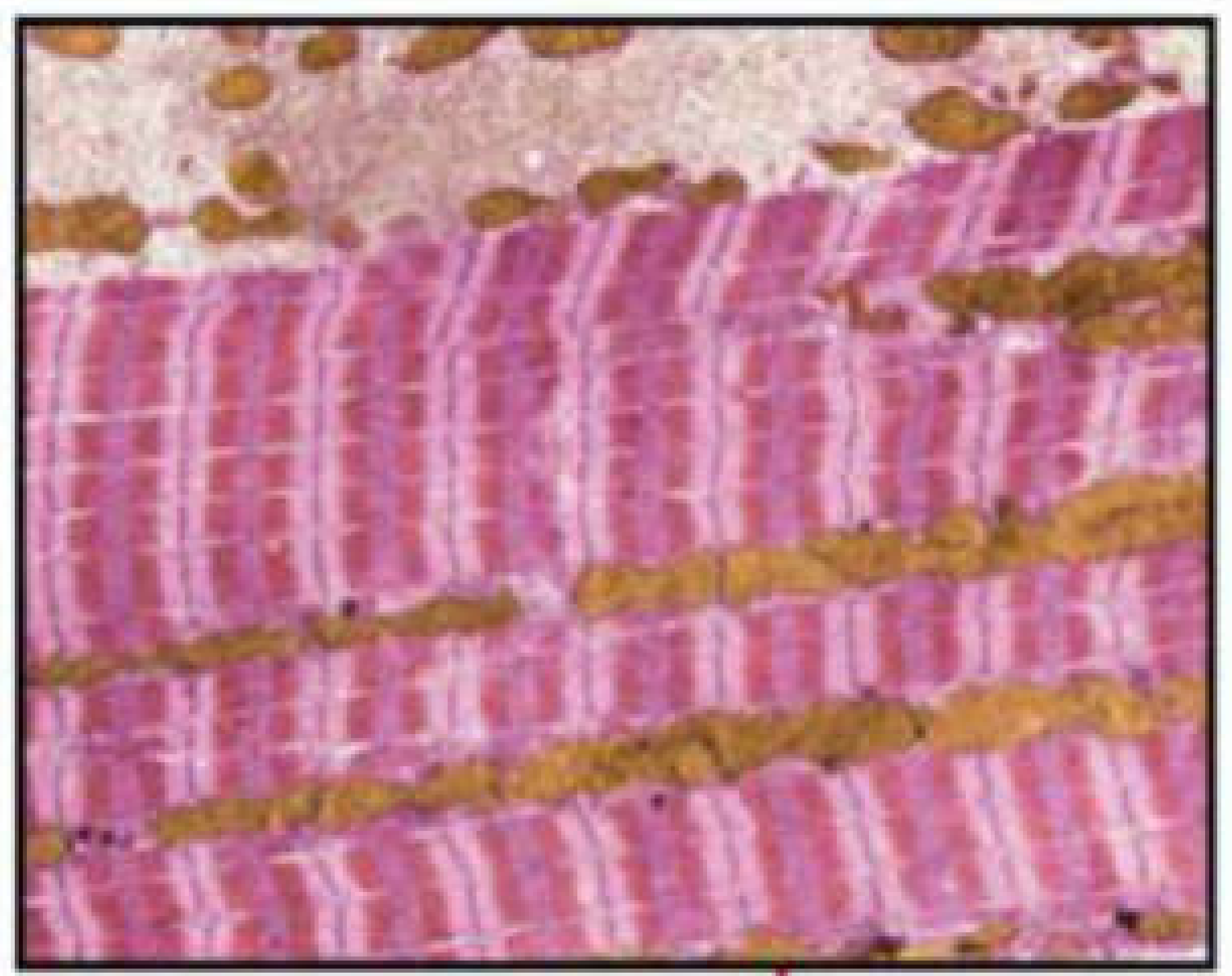
Muscle fibre
Each muscle fibre is an individual cell, packed with contractile proteins.

Epimysium
The entire muscle is enclosed in a tough, protective sheath of connective tissue.

Types of muscle

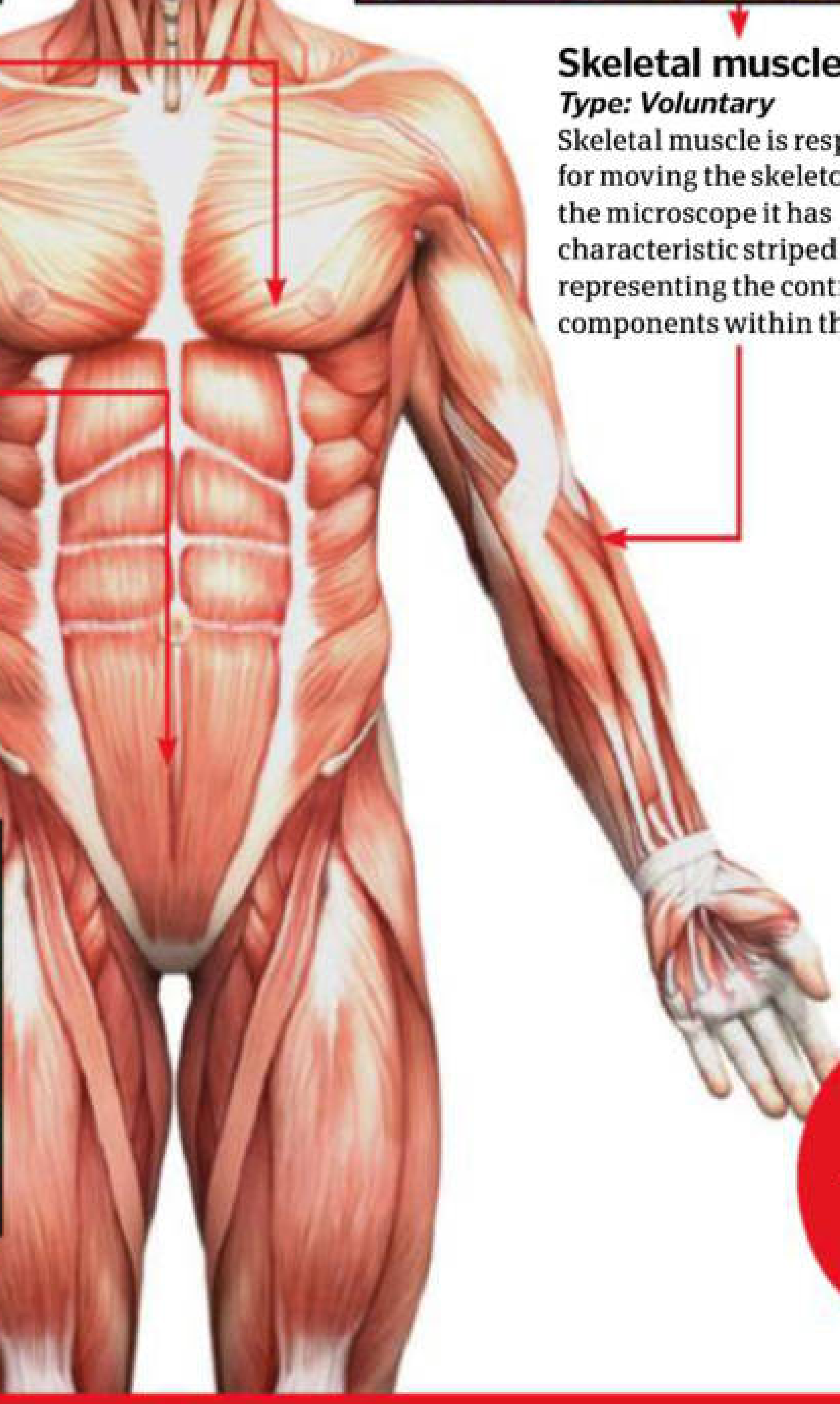


Cardiac muscle
Type: Heart
Like skeletal muscle, cardiac muscle is striated. Connections between the cells allow the contraction to pass in a co-ordinated wave across the heart.



Skeletal muscle
Type: Voluntary
Skeletal muscle is responsible for moving the skeleton. Under the microscope it has characteristic striped bands, representing the contractile components within the cells.

Smooth muscle
Type: Involuntary
The smooth muscle that lines internal structures is more elastic than skeletal muscle, allowing the intestines and bladder, etc, to contract even when stretched.



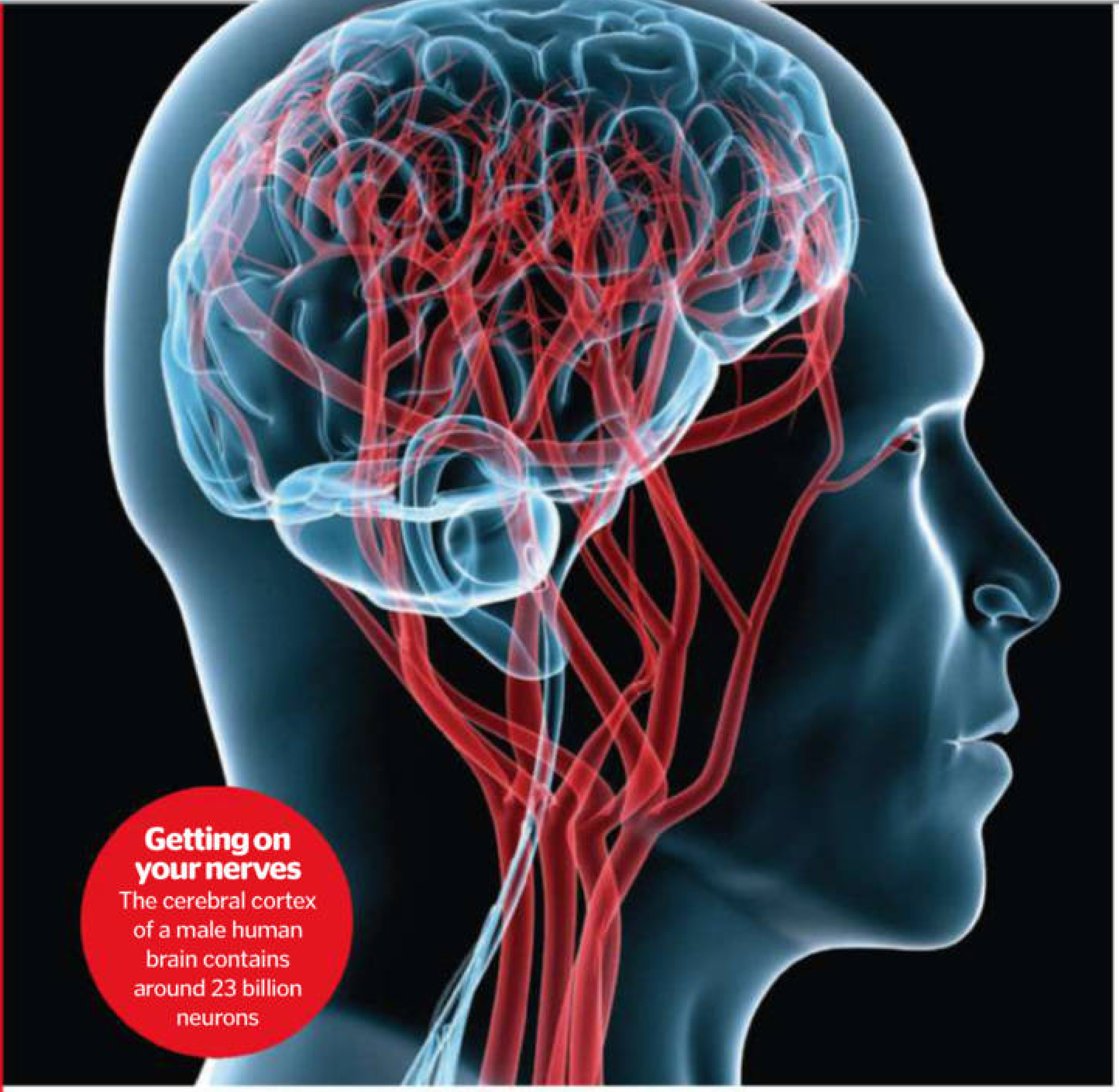
Why our bodies need a little fat

Adipose tissue provides the body with an energy reserve and also acts as a shock absorber – particularly on the soles of the feet. The fat cells – also known as adipocytes – contain a large lipid droplet, which takes up almost their entire volume, while their nuclei and other organelles are squashed on the perimeter.

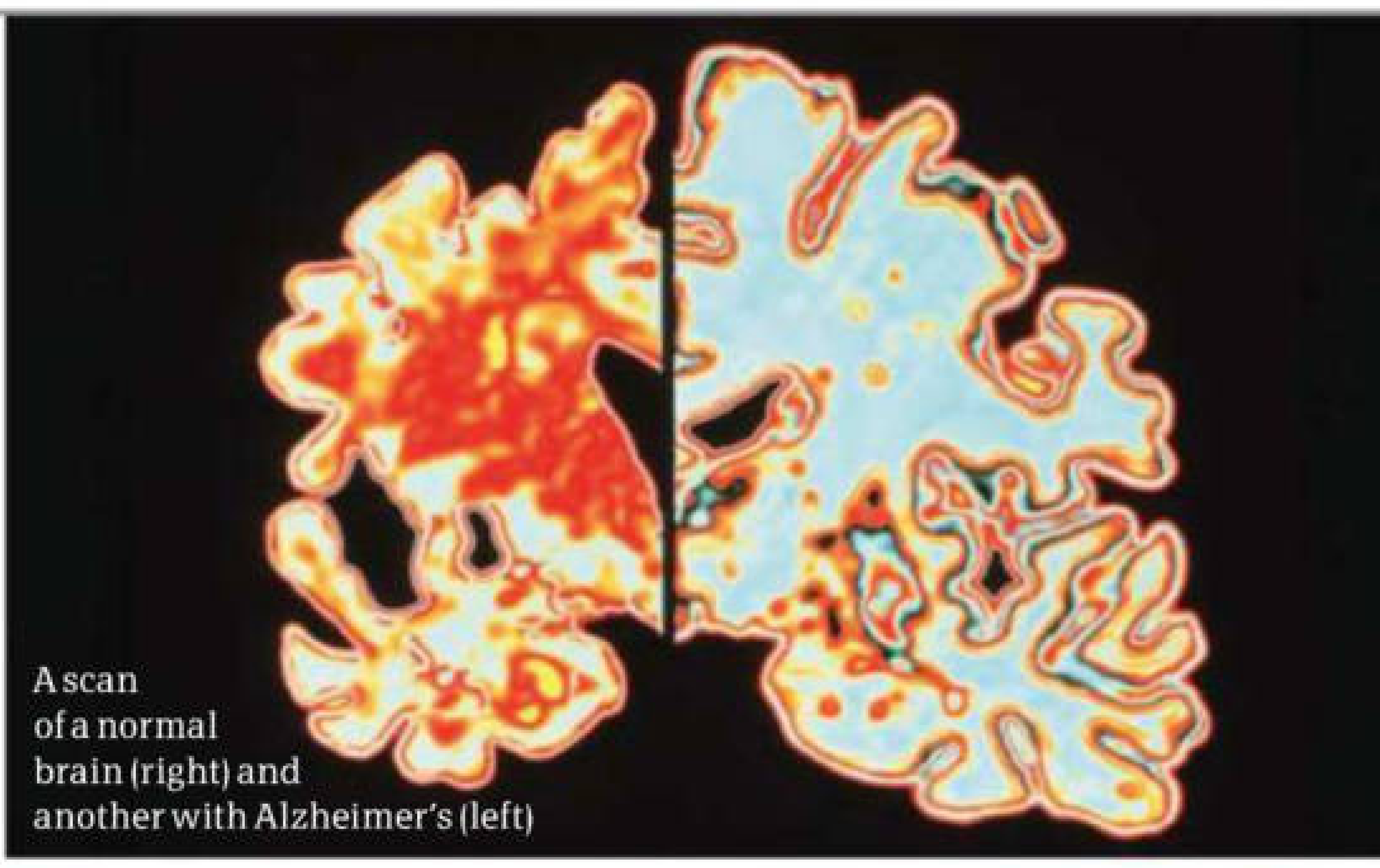
Adipocytes are not just used as storage sacks though; they have important metabolic and hormonal duties too, including involvement in the production of oestrogen.

Humans have a second type of fat tissue known as 'brown fat'. More commonly found in infants, brown fat provides a thermal blanket around the neck and the major blood vessels in the thorax. Brown fat cells are able to generate heat by a method known as uncoupling; instead of using glucose to make energy for the cell in the form of ATP, the brown fat can release the energy as heat. This is thought to be very important in newborns, who lack the ability to keep warm by shivering.

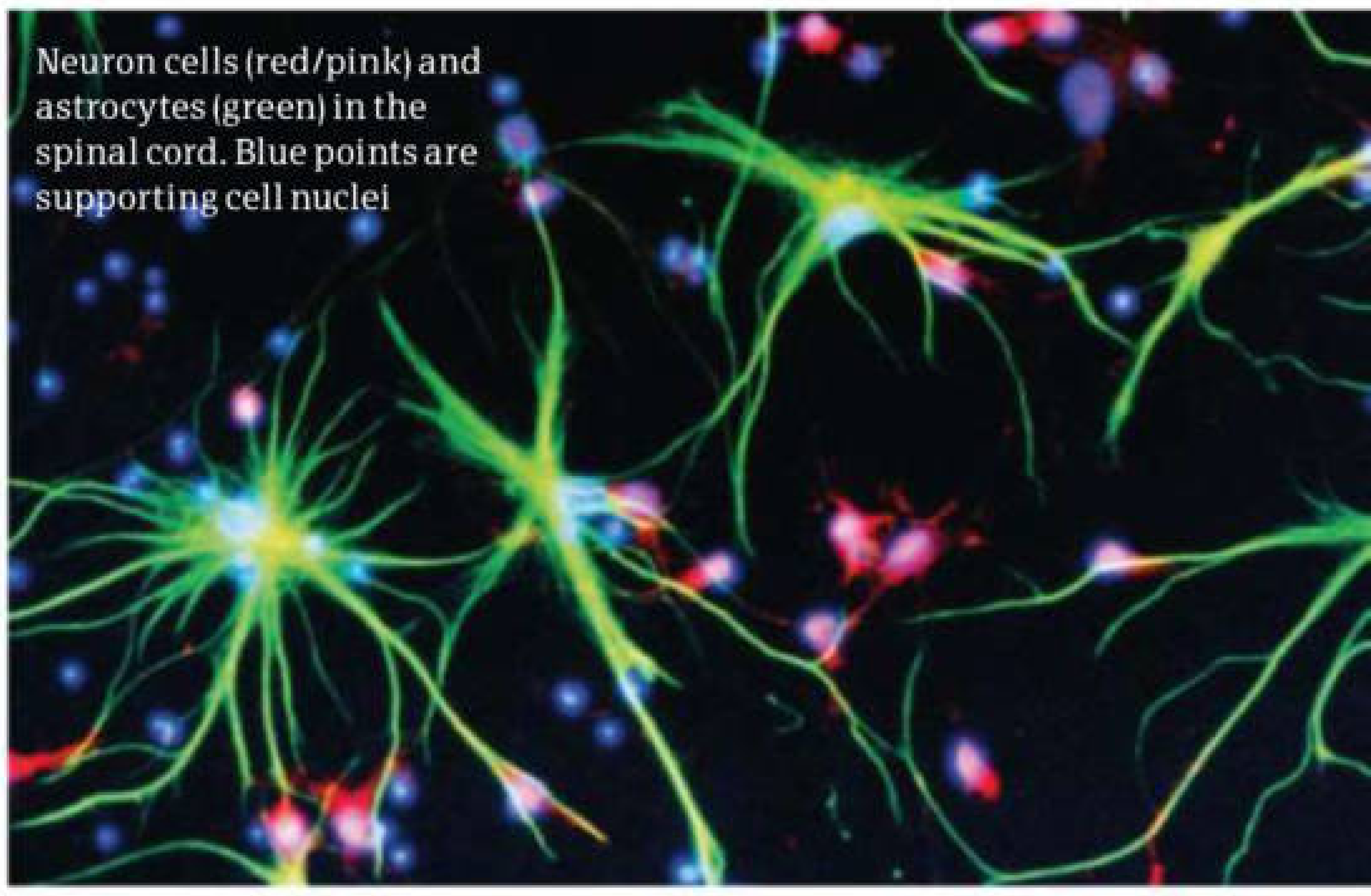
A fatty fact
The average human adult will have 30 billion fat cells



Getting on your nerves
The cerebral cortex of a male human brain contains around 23 billion neurons



A scan of a normal brain (right) and another with Alzheimer's (left)



Neuron cells (red/pink) and astrocytes (green) in the spinal cord. Blue points are supporting cell nuclei

Inside the brain

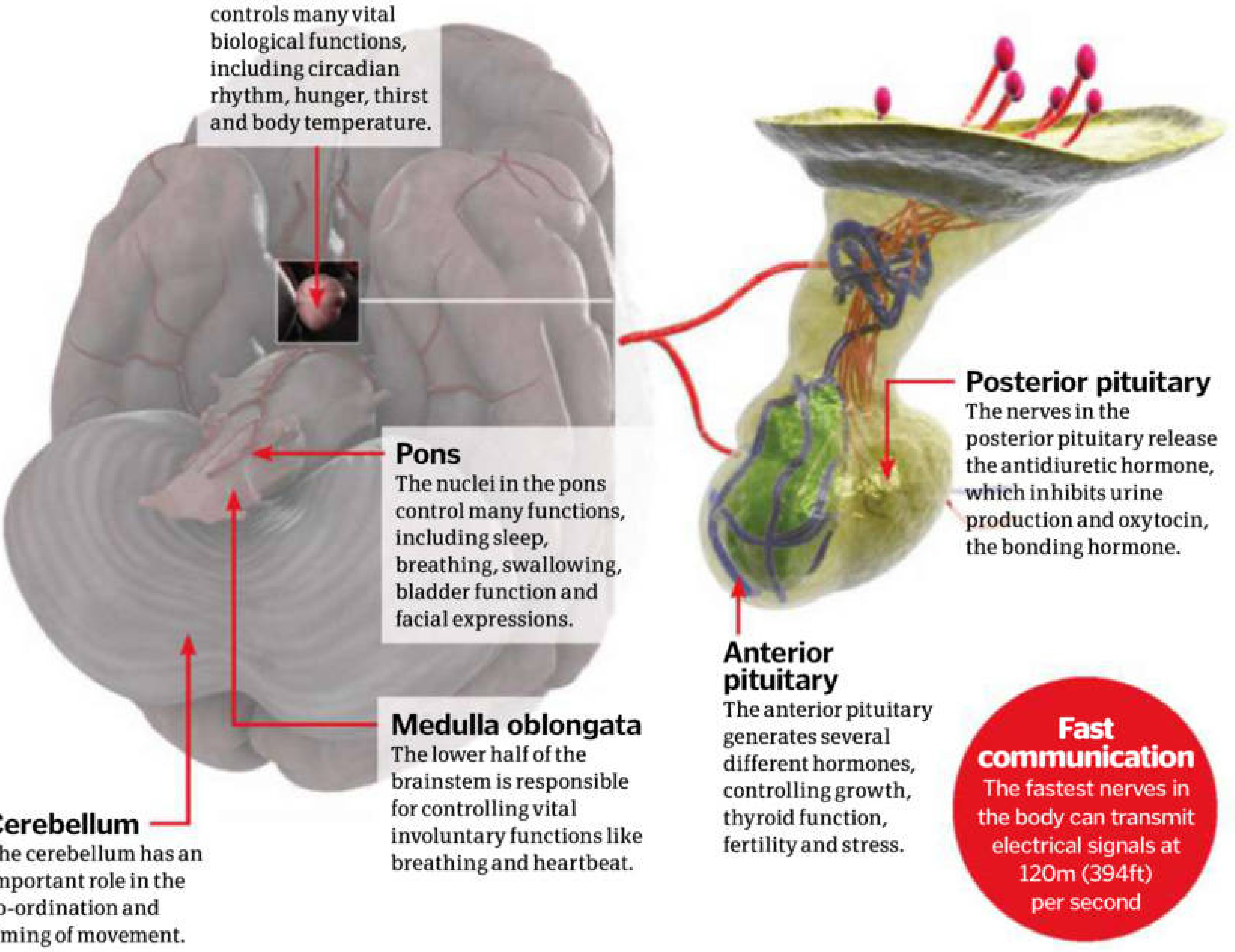
The brain is made up of two major types of cells: neurons and glial cells.

The neurons of the brain are highly specialised cells, interconnected by long, branching processes. They communicate through electrical 'action potentials', which can travel along the axons at speeds of 1-100 metres (3.3-328 feet) per second.

When an action potential reaches the synapse at the end of a nerve, it triggers the release of chemical transmitters, which bind to receptors on neighbouring nerves. Depending on the combination of neurotransmitters released – and the timing – the target nerve will fire, propagating the signal through the brain.

Glial cells, on the other hand, provide support to the neurons and have a variety of specialist functions. Astrocytes help to take up excess neurotransmitters from synapses, preventing neurons from damage due to excessive stimulation, while oligodendrocytes form fatty sheaths in order to insulate nerve cells in the brain and spinal cord.

The brain has significantly more protection than the other organs of the body. It is shielded from mechanical stress by the thick bones of the skull and is suspended in a cushion of cerebrospinal fluid. At the microscopic level, the brain is protected from potential hazards in the bloodstream by the blood-brain barrier – the cells lining the capillaries are joined together by tight junctions, controlling the passage of all molecules and bacteria into the organ.



Hypothalamus
The hypothalamus controls many vital biological functions, including circadian rhythm, hunger, thirst and body temperature.

Pons
The nuclei in the pons control many functions, including sleep, breathing, swallowing, bladder function and facial expressions.

Medulla oblongata
The lower half of the brainstem is responsible for controlling vital involuntary functions like breathing and heartbeat.

Cerebellum
The cerebellum has an important role in the co-ordination and timing of movement.

Posterior pituitary
The nerves in the posterior pituitary release the antidiuretic hormone, which inhibits urine production and oxytocin, the bonding hormone.

Anterior pituitary
The anterior pituitary generates several different hormones, controlling growth, thyroid function, fertility and stress.

Fast communication
The fastest nerves in the body can transmit electrical signals at 120m (394ft) per second

What role do hormones play in the body?

Angiotensin
Produced: Liver
Angiotensin causes blood vessels to constrict, raising blood pressure. ACE inhibitors that treat high blood pressure inhibit its activity.

Erythropoietin
Produced: Kidney
Cells in the kidney are sensitive to blood oxygen levels and can release this hormone to encourage production of new red blood cells.

Ghrelin
Produced: Stomach
A chemical signal produced mainly by the stomach. It acts as an appetite stimulant, making you feel either hungry or full up.

Oxytocin
Produced: Mainly in the brain
This is also known as the 'bonding hormone' and is produced at high levels during and after childbirth.

Cortisol
Produced: Adrenal glands
The 'stress hormone' helps to increase blood sugar by promoting the breakdown of fat and muscle tissue.

Leptin
Produced: Fat
Made by fat tissue, leptin plays a fundamental role in acting as a fuel gauge and telling the brain just how much fat is stored in the body.

The ageing body

The human body changes as it ages and the peak time for organ functionality is thought to be around the age of 30. The body has amazing capacity for regeneration, but cells can only divide a finite number of times, and as we get older our ability to repair damaged tissue decreases.

Dramatic changes, such as the menopause, produce obvious effects on the body. Female sex hormones are not just involved in reproduction, but also play a role in other processes, such as the maintenance of bone density. In the absence of oestrogen, bone mineral density decreases, which can lead to osteoporosis. A similar, but less dramatic, effect can be seen in men as testosterone levels begin to drop.

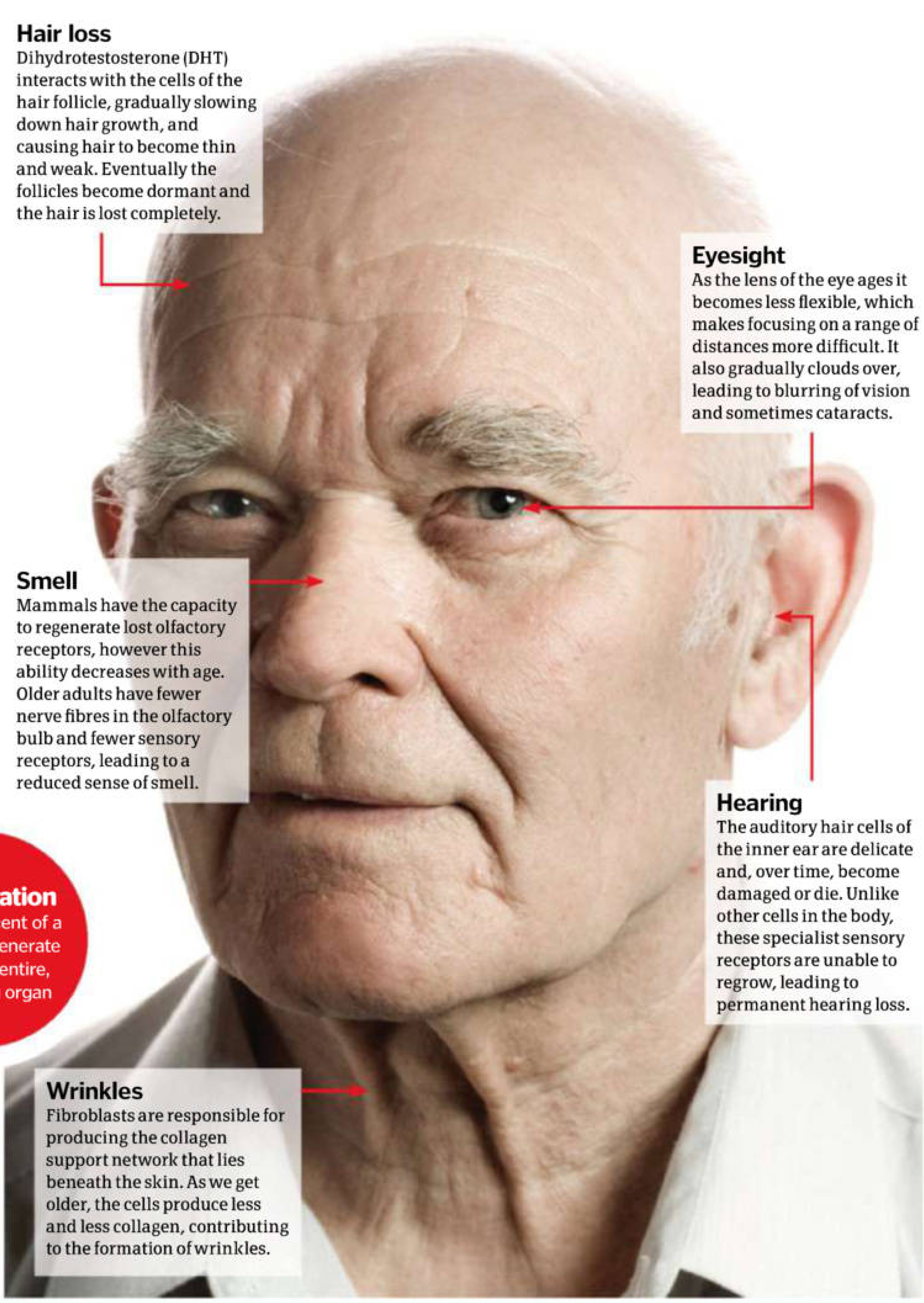
Similar decline in functionality can be observed throughout the human body; collagen in the skin begins to decrease, insulated axons in the brain shorten, and DNA damage accumulates, leading to an ever greater risk of cancer.

However, it's not all bad. Life expectancy is on the increase, and scientists are coming closer to understanding – and being able to slow – the complex processes of human ageing.

As the body gets older it becomes more susceptible to faulty cells that cause cancer

Arthritis is the main cause of disability in over-55s in industrialised countries

Regeneration
Just 25 per cent of a liver can regenerate to form an entire, functioning organ



Hair loss
Dihydrotestosterone (DHT) interacts with the cells of the hair follicle, gradually slowing down hair growth, and causing hair to become thin and weak. Eventually the follicles become dormant and the hair is lost completely.

Eyesight
As the lens of the eye ages it becomes less flexible, which makes focusing on a range of distances more difficult. It also gradually clouds over, leading to blurring of vision and sometimes cataracts.

Smell
Mammals have the capacity to regenerate lost olfactory receptors, however this ability decreases with age. Older adults have fewer nerve fibres in the olfactory bulb and fewer sensory receptors, leading to a reduced sense of smell.

Hearing
The auditory hair cells of the inner ear are delicate and, over time, become damaged or die. Unlike other cells in the body, these specialist sensory receptors are unable to regrow, leading to permanent hearing loss.

Wrinkles
Fibroblasts are responsible for producing the collagen support network that lies beneath the skin. As we get older, the cells produce less and less collagen, contributing to the formation of wrinkles.

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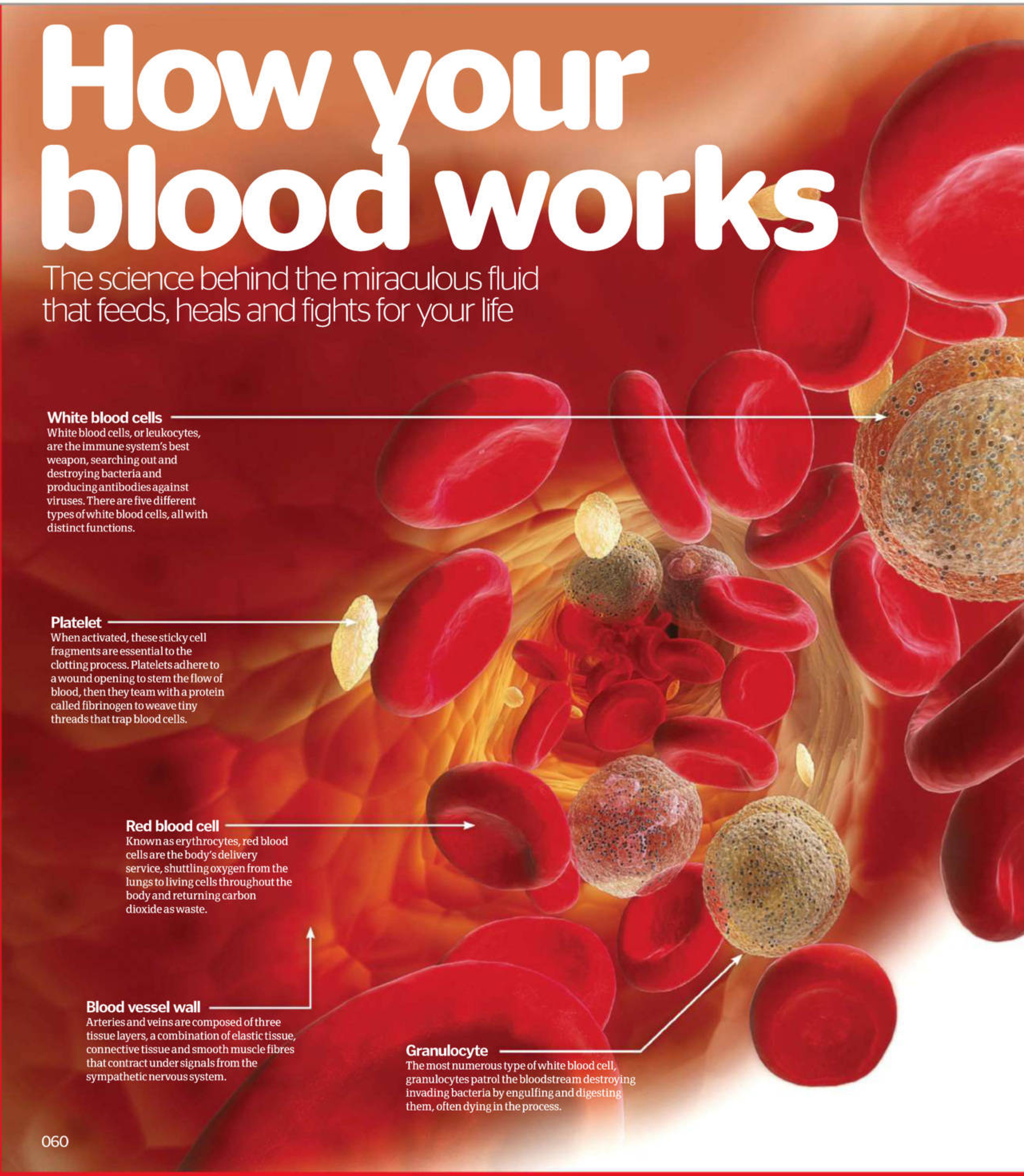
How your blood works

The science behind the miraculous fluid that feeds, heals and fights for your life



White blood cells
White blood cells, or leukocytes, are the immune system's best weapon, searching out and destroying bacteria and producing antibodies against viruses. There are five different types of white blood cells, all with distinct functions.

Platelet
When activated, these sticky cell fragments are essential to the clotting process. Platelets adhere to a wound opening to stem the flow of blood, then they team with a protein called fibrinogen to weave tiny threads that trap blood cells.

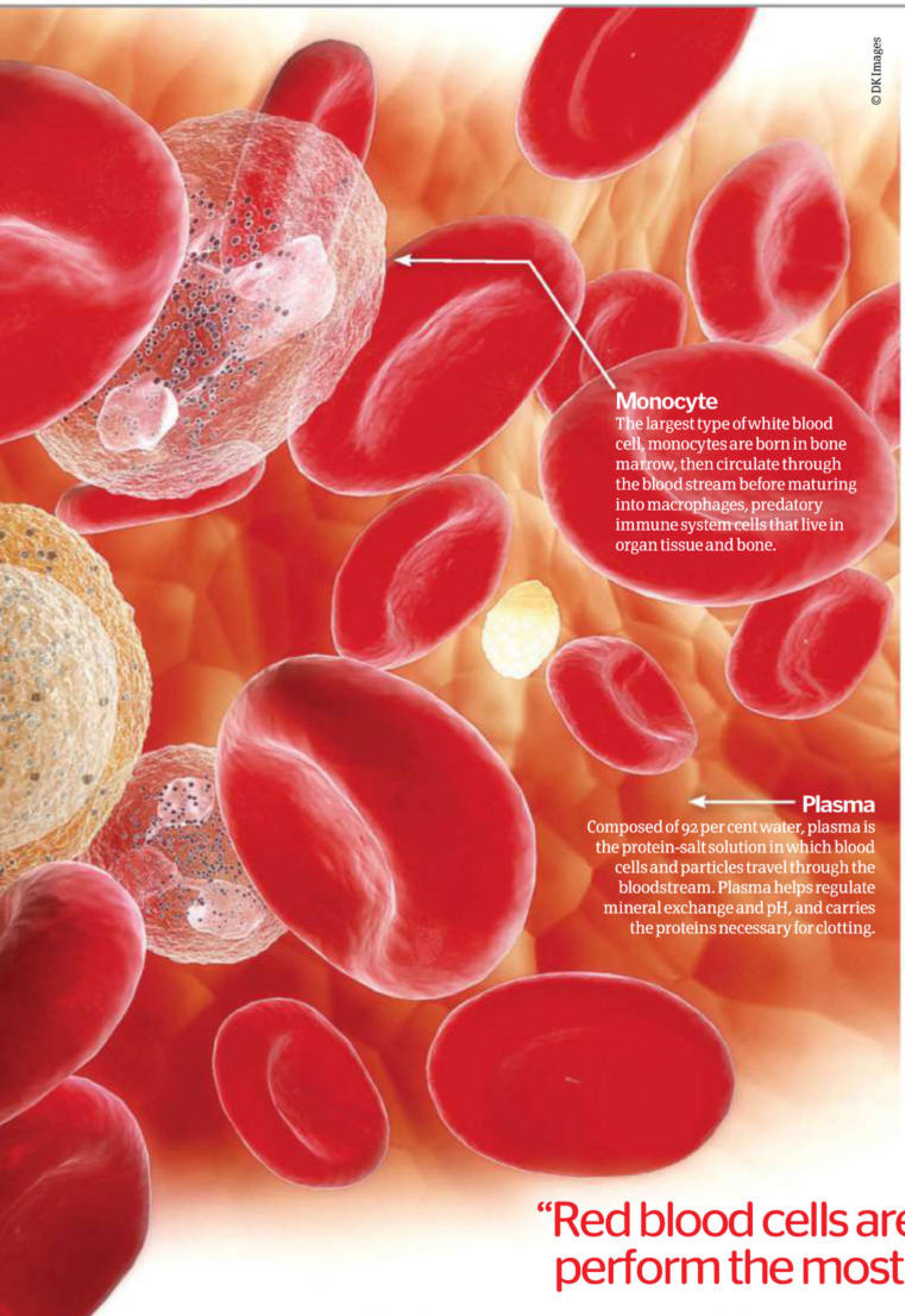
Red blood cell
Known as erythrocytes, red blood cells are the body's delivery service, shuttling oxygen from the lungs to living cells throughout the body and returning carbon dioxide as waste.

Blood vessel wall
Arteries and veins are composed of three tissue layers, a combination of elastic tissue, connective tissue and smooth muscle fibres that contract under signals from the sympathetic nervous system.

Granulocyte
The most numerous type of white blood cell, granulocytes patrol the bloodstream destroying invading bacteria by engulfing and digesting them, often dying in the process.

Components of blood

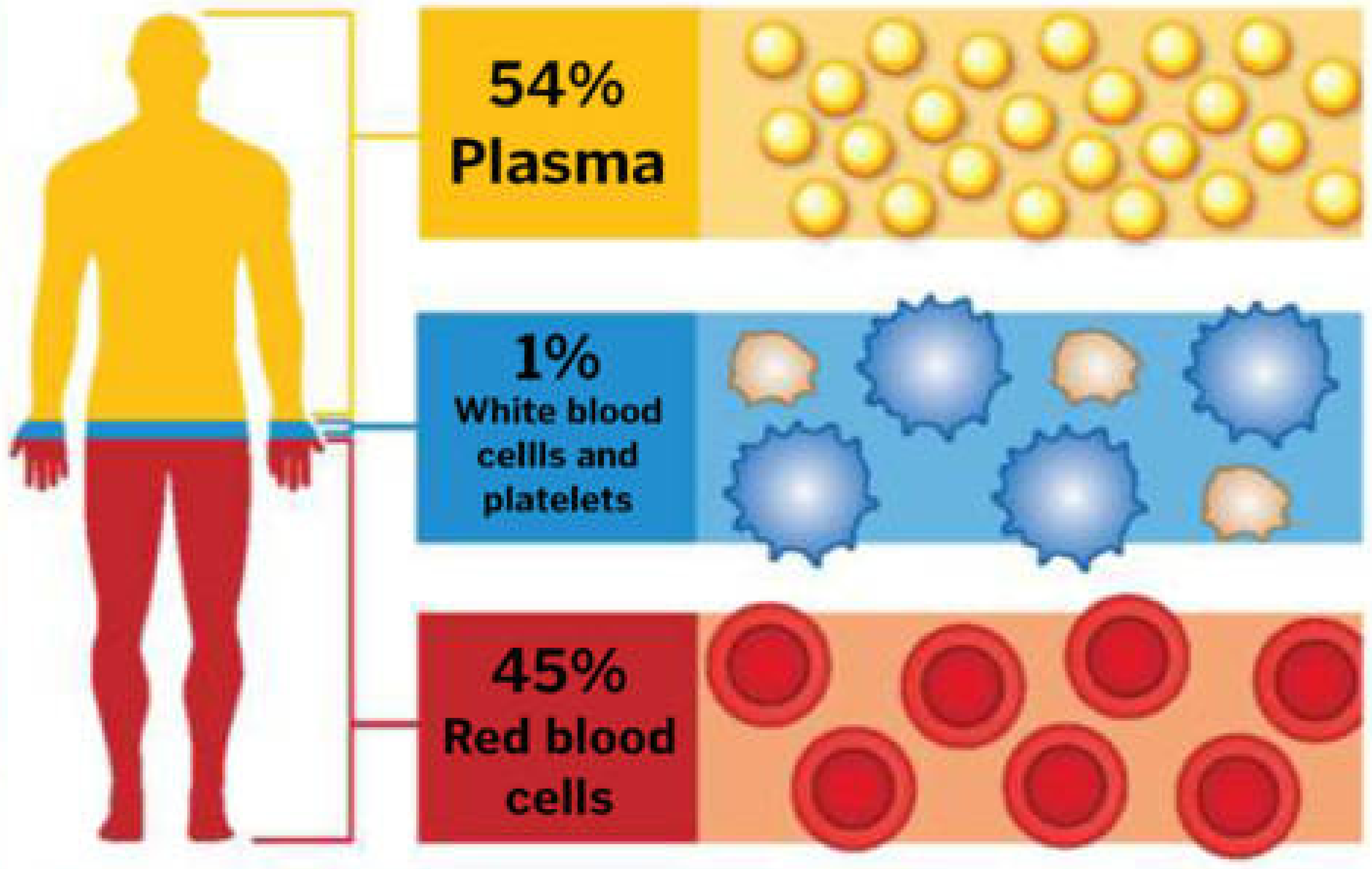
Blood is a mix of solids and liquids, a blend of highly specialised cells and particles suspended in a protein-rich fluid called plasma. Red blood cells dominate the mix, carrying oxygen to living tissue and returning carbon dioxide to the lungs. For every 600 red blood cells, there is a single white blood cell, of which there are five different kinds. Cell fragments called platelets use their irregular surface to cling to vessel walls and initiate the clotting process.

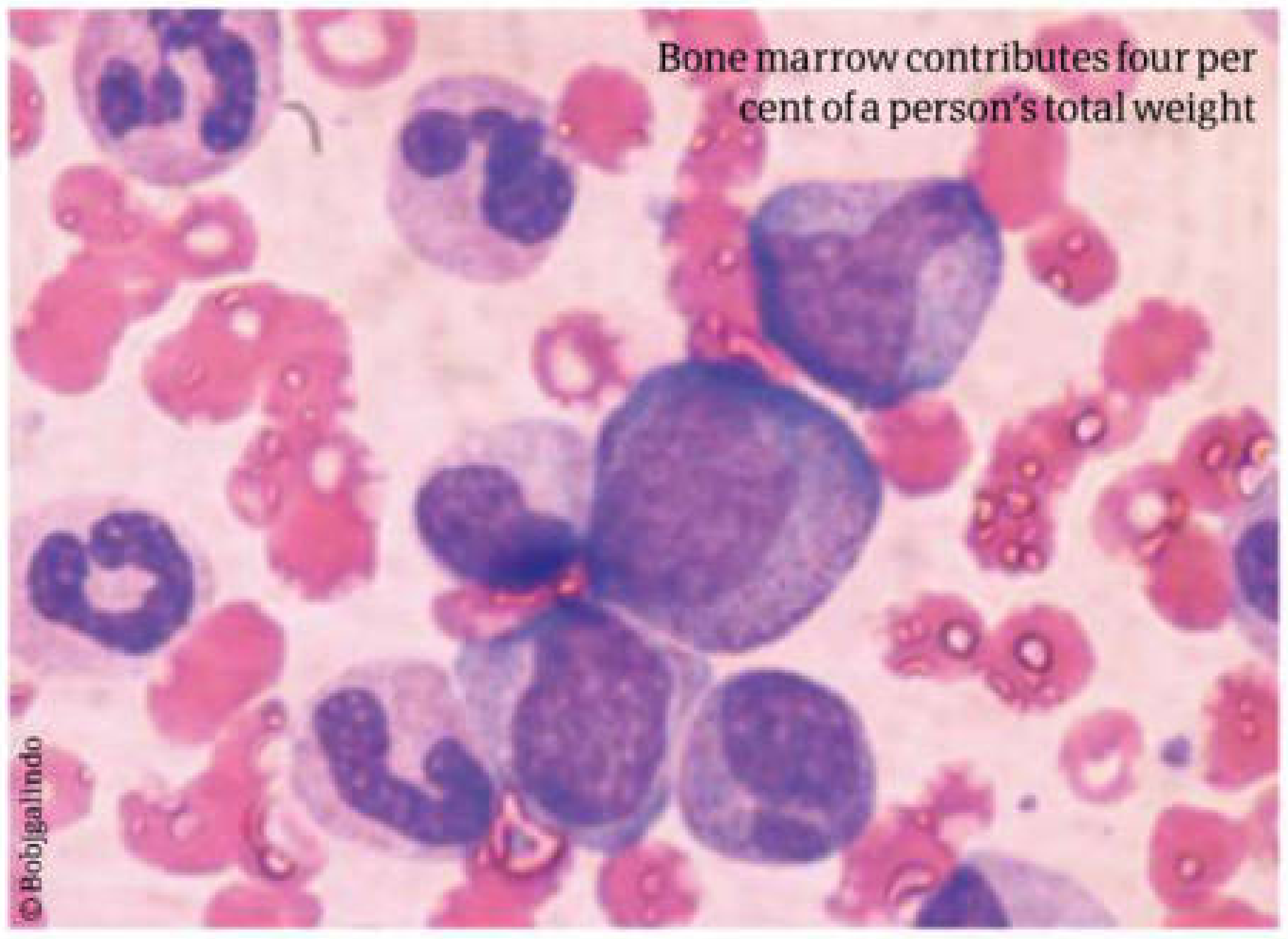


© DK Images

Monocyte
The largest type of white blood cell, monocytes are born in bone marrow, then circulate through the blood stream before maturing into macrophages, predatory immune system cells that live in organ tissue and bone.

Plasma
Composed of 92 per cent water, plasma is the protein-salt solution in which blood cells and particles travel through the bloodstream. Plasma helps regulate mineral exchange and pH, and carries the proteins necessary for clotting.





Bone marrow contributes four per cent of a person's total weight

© Bobjgalindo

> "Red blood cells are so numerous because they perform the most essential function of blood"

Blood is the river of life. It feeds oxygen and essential nutrients to living cells in the body and carries away their waste. It transports the foot soldiers of the immune system, white blood cells, which seek out and destroy invading bacteria and parasites. And it speeds platelets to the site of injury or tissue damage, triggering the body's miraculous process of self-repair.

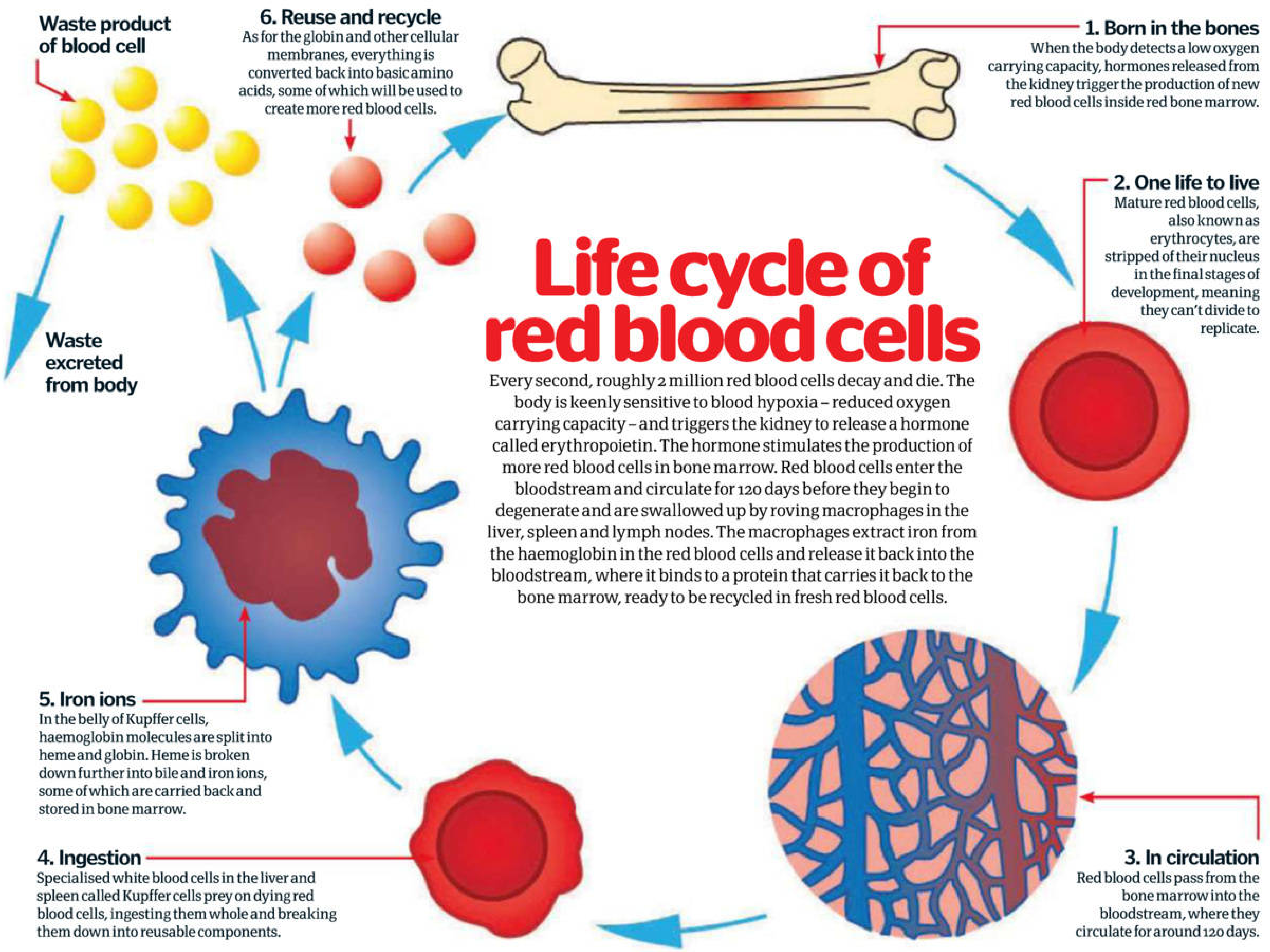
Blood looks like a thick, homogenous fluid, but it's more like a watery current of plasma – which is a straw-coloured, protein-rich fluid – carrying billions of microscopic solids consisting of red blood cells, white blood cells and cell fragments called platelets. The distribution is far from equal. Over half of blood is plasma, 45 per cent is red blood cells and a tiny fragment, less than one per cent, is composed of white blood cells and platelets.

Red blood cells are so numerous because they perform the most essential function of blood, which is to deliver oxygen to every cell in the body and carry away carbon dioxide. As an adult, all of your red blood cells are produced in red bone marrow, the spongy tissue in the bulbous ends of long bones and at the centre of flat bones like hips and ribs. Inside the marrow, red blood cells start out as undifferentiated stem cells called hemocytoblasts. If the body detects a minuscule drop in oxygen carrying capacity, a hormone is released from the kidneys that triggers the stem cells to become red blood cells. Because red blood cells only live 120 days, the supply must be continuously replenished; roughly 2 million red blood cells are born to replace dying ones every second.

A mature red blood cell does not have a nucleus. The nucleus comes out during the final stages of the cell's two-day development before taking on the shape of a concave, doughnut-like disc. Like all cells, red blood cells consist mostly of water, but 97 per cent of their solid matter is made up of haemoglobin, which is a complex protein that carries four atoms of iron. Those iron atoms have the ability to form ▶

Life cycle of red blood cells

Every second, roughly 2 million red blood cells decay and die. The body is keenly sensitive to blood hypoxia – reduced oxygen carrying capacity – and triggers the kidney to release a hormone called erythropoietin. The hormone stimulates the production of more red blood cells in bone marrow. Red blood cells enter the bloodstream and circulate for 120 days before they begin to degenerate and are swallowed up by roving macrophages in the liver, spleen and lymph nodes. The macrophages extract iron from the haemoglobin in the red blood cells and release it back into the bloodstream, where it binds to a protein that carries it back to the bone marrow, ready to be recycled in fresh red blood cells.



1. Born in the bones
When the body detects a low oxygen carrying capacity, hormones released from the kidney trigger the production of new red blood cells inside red bone marrow.

2. One life to live
Mature red blood cells, also known as erythrocytes, are stripped of their nucleus in the final stages of development, meaning they can't divide to replicate.

3. In circulation
Red blood cells pass from the bone marrow into the bloodstream, where they circulate for around 120 days.

4. Ingestion
Specialised white blood cells in the liver and spleen called Kupffer cells prey on dying red blood cells, ingesting them whole and breaking them down into reusable components.

5. Iron ions
In the belly of Kupffer cells, haemoglobin molecules are split into heme and globin. Heme is broken down further into bile and iron ions, some of which are carried back and stored in bone marrow.

6. Reuse and recycle
As for the globin and other cellular membranes, everything is converted back into basic amino acids, some of which will be used to create more red blood cells.

▶ loose, reversible bonds with both oxygen and carbon dioxide – think of them as weak magnets – and this is what makes red blood cells such an effective transport system for respiratory gasses. Haemoglobin, which turns a bright red colour whenever it is oxygenated, is what gives blood its characteristic crimson colour.

In order to provide oxygen to every living cell in the body, red blood cells must be pumped through the body's circulatory system. The right side of the heart pumps CO_2-heavy blood into the lungs, where it releases its waste gasses and picks up oxygen. The left side of the heart then pumps the freshly oxygenated blood back out into the body through a system of arteries and capillaries, some of which are as narrow as a single cell. As the red blood cells release their oxygen, they pick up carbon dioxide molecules and then course through the veins back toward the heart, where they are pumped back into the lungs to 'exhale' the excess CO_2 and collect some more precious O_2.

White blood cells are greatly outnumbered by red blood cells, but they are critical to the function of the immune system. Most white blood cells are also produced in red bone marrow, but white blood cells – unlike red blood cells – come in five different varieties, each with its own specialised immune function. The first three varieties, collectively called granulocytes, engulf and digest bacteria and parasites, and play a role in allergic reactions. Lymphocytes, another type of white blood cell, produce antibodies that build up our immunity to repeat intruders. And monocytes, the largest of the white blood cells, enter organ tissue and become macrophages, microbes that ingest bad bacteria and help break down dead red blood cells into reusable parts.

Platelets aren't cells at all, but fragments of much larger stem cells found in bone marrow. In their resting state, they look like smooth oval plates, but when activated to form a clot they take on an irregular form with many protruding arms called pseudopods. This shape helps them stick to blood vessel walls as well as to each other, forming a physical barrier around wound sites. With the help of proteins and clotting factors found in plasma, platelets weave a mesh of fibrin that stems blood loss through the wound and triggers the formation of new collagen and skin cells.

But even these three functions of blood – oxygen supplier, immune system defender and wound healer – only begin to scratch the surface of the critical role of blood in each and every bodily process. When blood circulates through the small intestine, it absorbs sugars from digested food, which are transported to the liver to be stored as energy. When blood passes through the kidneys, it is scrubbed of excess urea and salts, waste that will leave the body as urine. The proteins in plasma transport vitamins, hormones, enzymes, sugar and electrolytes. Pause for a second to listen to your pumping heart and be thankful for the river of life coursing through your veins.

Blood disorders

Blood is a delicate balancing act, with the body constantly regulating oxygen flow, iron content and clotting ability. Unfortunately, there are several genetic conditions and chronic illnesses that can disturb the balance, sometimes with deadly consequences.

Haemophilia

This rare genetic blood disorder severely inhibits the clotting mechanism of blood, causing excessive bleeding, internal bruising and joint problems. Platelets are essential to the clotting and healing process, producing threads of fibrin with help from proteins in the bloodstream called clotting factors. People who suffer from haemophilia – almost exclusively males – are missing one of those clotting factors, making it difficult to seal off blood vessels after even minor injuries.

Thalassemia

Another rare blood disorder affecting 100,000 newborns worldwide each year, thalassemia inhibits the production of haemoglobin, leading to severe anaemia. People who are born with the most serious form of the disease, also called Cooley's anaemia, suffer from enlarged hearts, livers and spleens, and brittle bones. The most effective treatment is frequent blood transfusions, although a few lucky patients have been cured through bone marrow transplants from perfectly matching donors.

Thalassemia affects 100,000 newborns a year worldwide

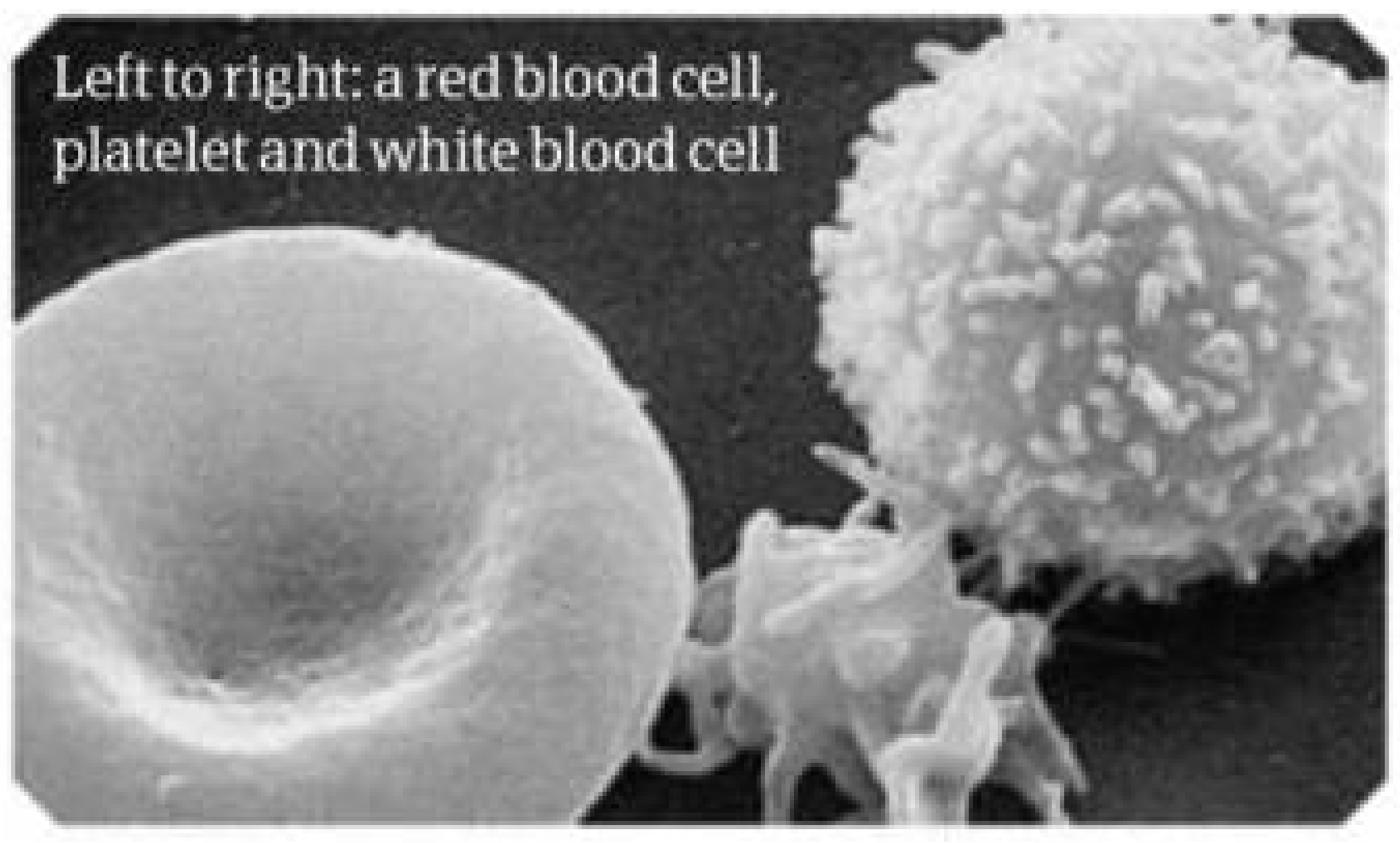
Sickle cell anaemia

Anaemia is the name for any blood disorder that results in a dangerously low red blood cell count. In sickle cell anaemia, which afflicts one out of every 625 children of African descent, red blood cells elongate into a sickle shape after releasing their oxygen. The sickle-shaped cells die prematurely, leading to anaemia, or sometimes lodge in blood vessels, causing terrible pain and even organ damage. Interestingly, people who carry only one gene for sickle cell anaemia are immune to malaria.

©Science Photo Library

Hemochromatosis

One of the most common genetic blood disorders, hemochromatosis is the medical term for "iron overload," in which your body absorbs and stores too much iron from food. Severity varies wildly, and many people experience few symptoms, but others suffer serious liver damage or scarring (cirrhosis), irregular heartbeat, diabetes and even heart failure. Symptoms can be aggravated by taking too much vitamin C.



Left to right: a red blood cell, platelet and white blood cell

Deep vein thrombosis

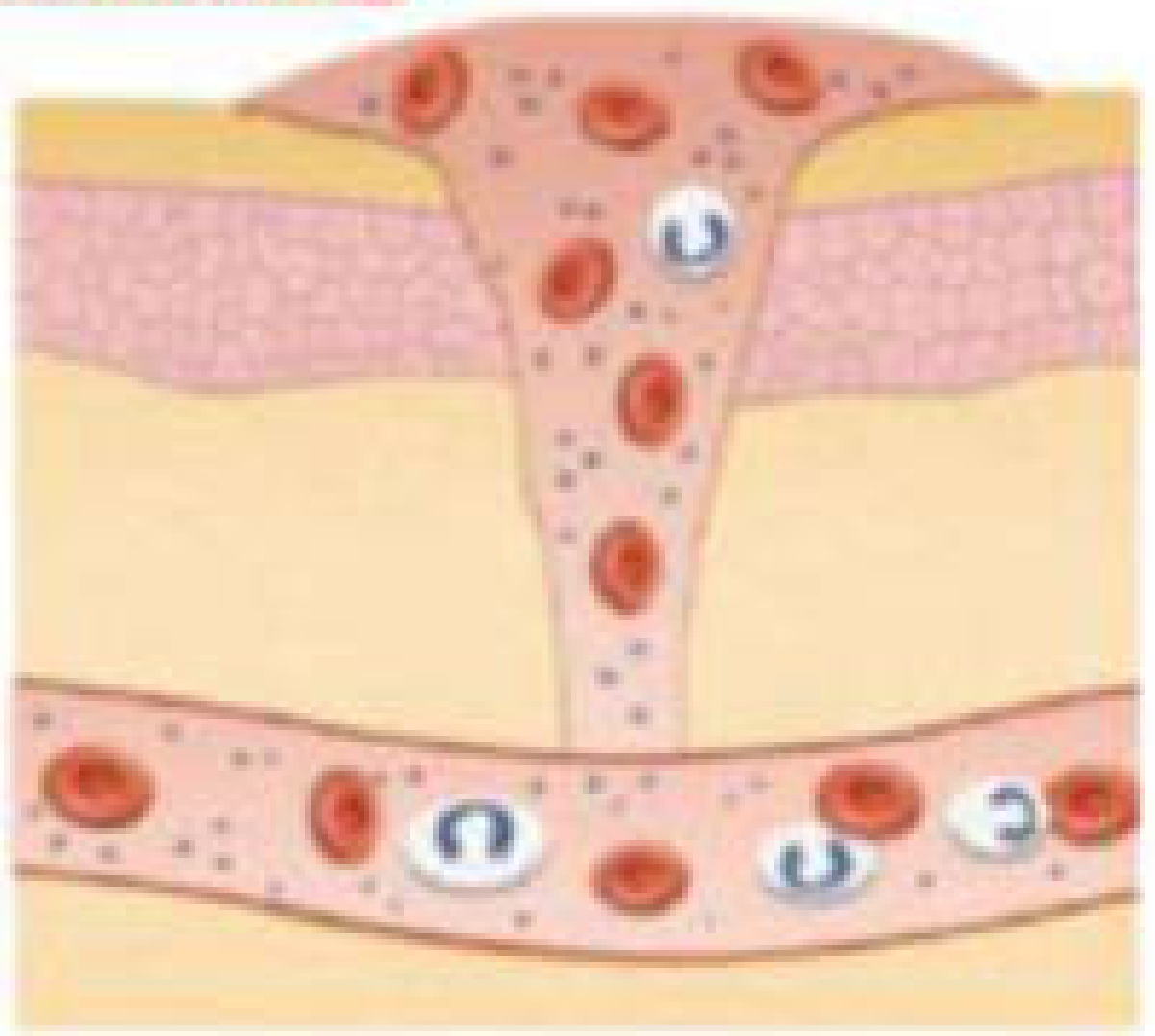
Thrombosis is the medical term for any blood clot that is large enough to block a blood vessel. When a blood clot forms in the large, deep veins of the upper thigh, it's called deep vein thrombosis. If such a clot breaks free, it can circulate through the bloodstream, pass through the heart and become lodged in arteries in the lung, causing a pulmonary embolism. Such a blockage can severely damage portions of the lungs, and multiple embolisms can even be fatal.

Blood and healing

More than a one-trick pony, your blood is a vital cog in the healing process

Think of blood as the body's emergency response team to an injury. Platelets emit signals that encourage blood vessels to contract, stemming blood loss, and then collect around the wound, reacting with a protein in plasma to form fibrin, a tissue that weaves into a mesh. Blood flow returns and white blood cells begin to hunt for bacteria. Fibroblasts create beds of fresh collagen and capillaries to fuel skin cell growth. The scab begins to contract, pulling the growing skin cells together until damaged tissue is replaced.

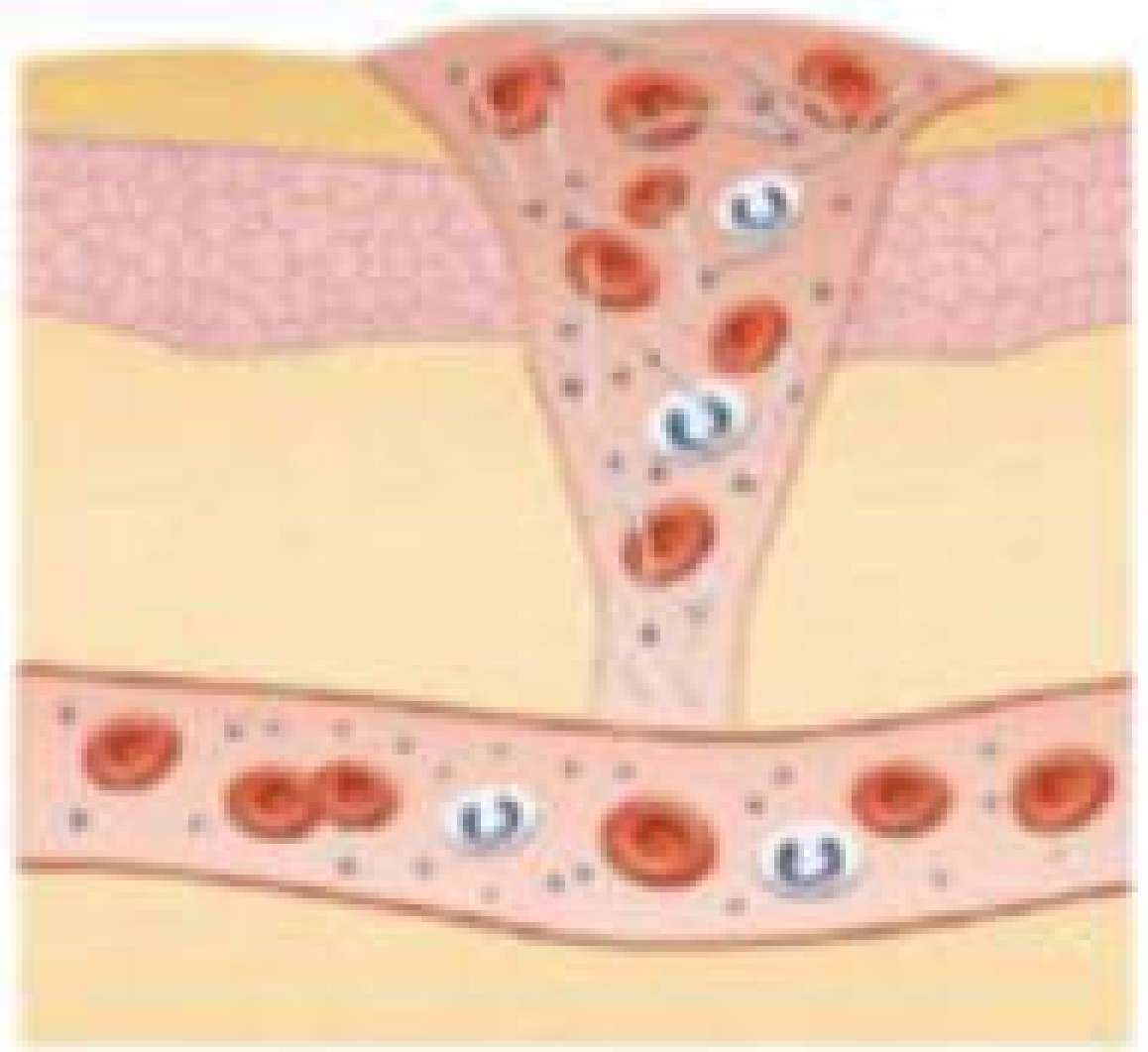
STAGE 1



INJURY

When the skin surface is cut, torn or scraped deeply enough, blood seeps from broken blood vessels to fill the wound. To stem the flow of bleeding, the blood vessels around the wound constrict.

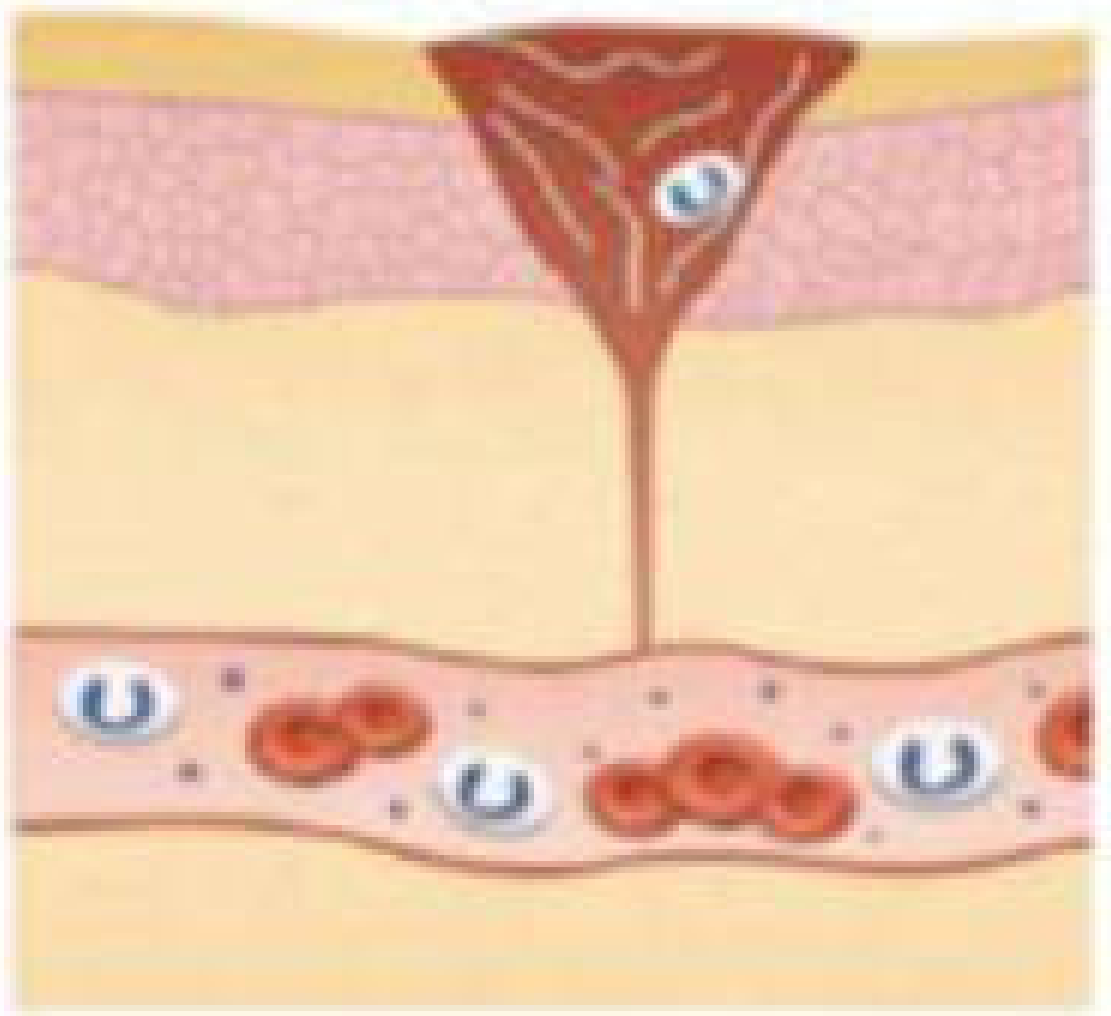
STAGE 2



HAEMOSTASIS

Activated platelets aggregate around the surface of the wound, stimulating vasoconstriction. Platelets react with a protein in plasma to form fibrin, a web-like mesh of stringy tissue.

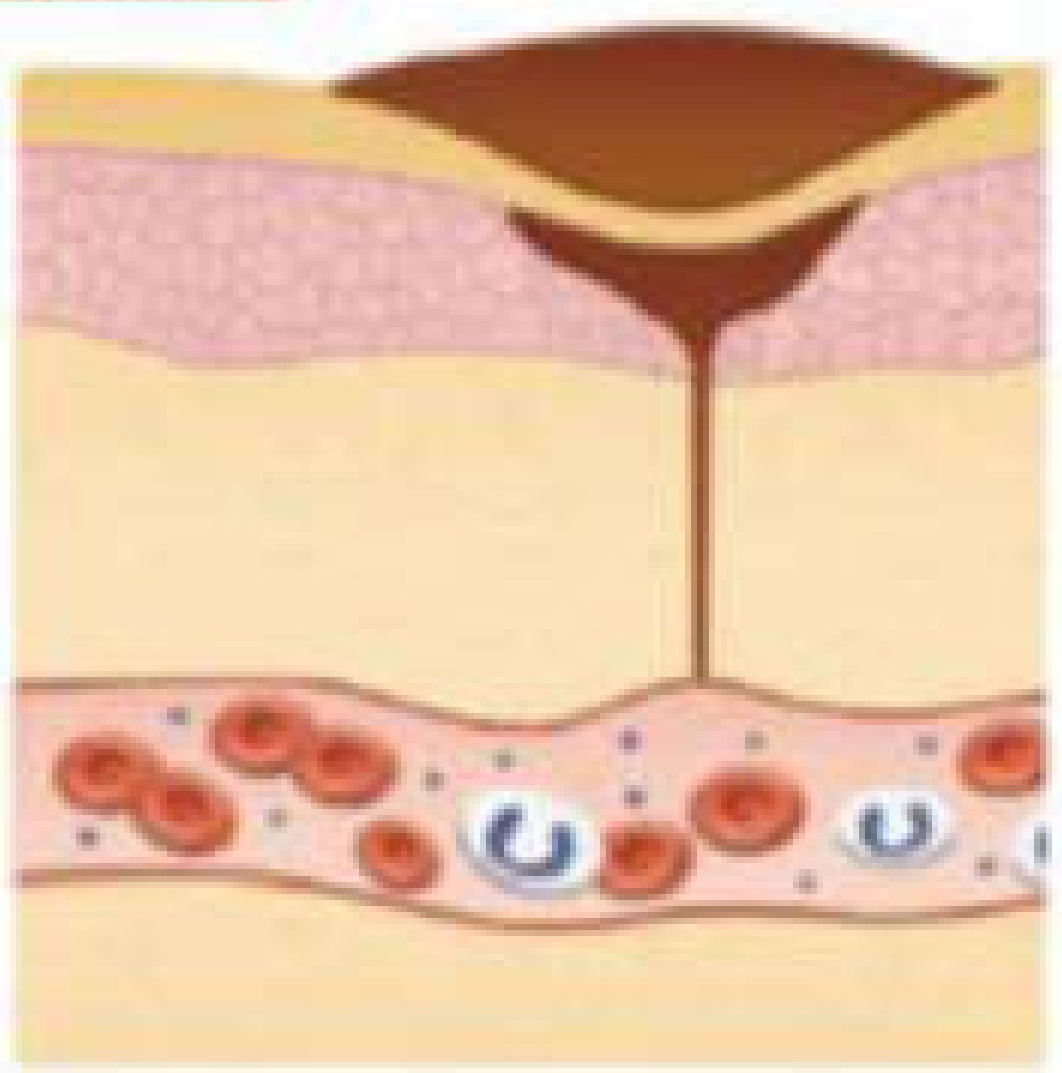
STAGE 3



INFLAMMATORY STAGE

Once the wound is capped with a drying clot, blood vessels re-open and release plasma and white blood cells into the damaged tissue. Macrophages digest harmful bacteria and dead cells.

STAGE 4



PROLIFERATIVE STAGE

Fibroblasts lay fresh layers of collagen inside the wound and capillaries begin to supply blood for the forming of new skin cells. Fibrin strands and collagen pull the sides of the wound together.

Human respiration

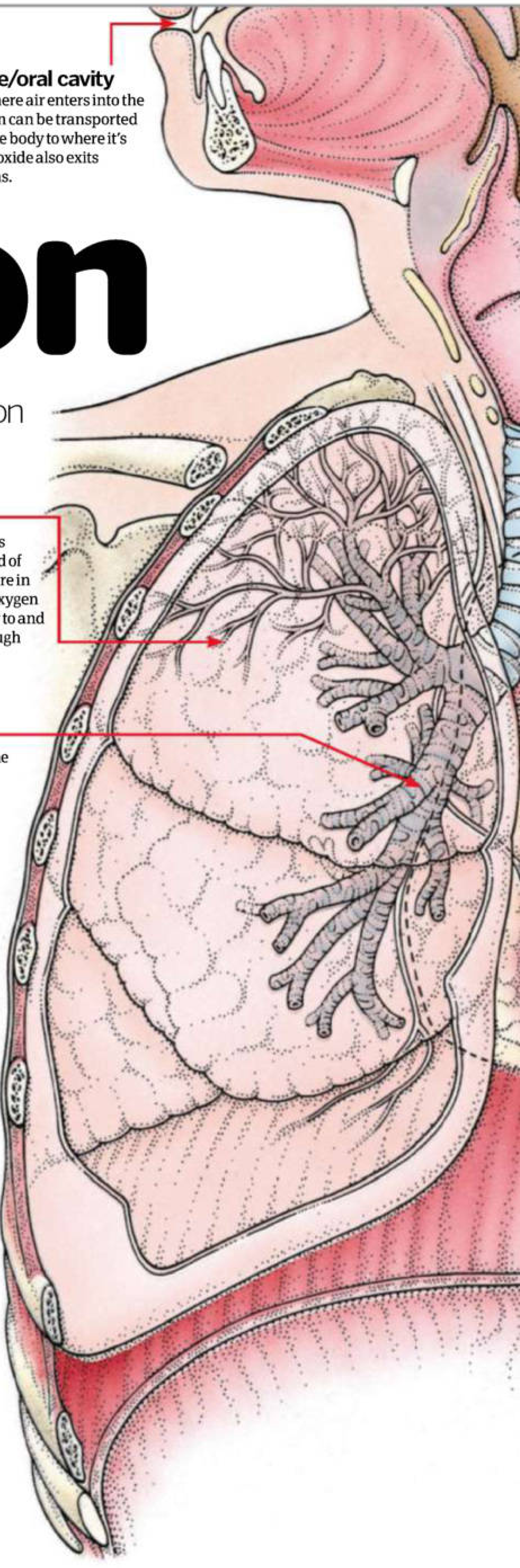
Respiration is crucial to an organism's survival. The process of respiration is the transportation of oxygen from the air that surrounds us into the tissue cells of our body so that energy can be broken down

The primary organs used for respiration in humans are the lungs. Humans have two lungs, with the left lung being divided into two lobes and the right into three. The lungs have between 300–500 million alveoli, which is where gas exchange occurs.

Respiration of oxygen breaks into four main stages: ventilation, pulmonary gas exchange, gas transportation and peripheral gas exchange. Each stage is crucial in getting oxygen to the body's tissue, and removing carbon dioxide. Ventilation and gas transportation need energy to occur, as the diaphragm and the heart are used to facilitate these actions whereas gas exchanging is passive. As air is drawn into the lungs at a rate of between 10-20 breaths per minute while resting, through either your mouth or nose by diaphragm contraction, and travels through the pharynx, then the larynx, down the trachea, and into one of the two main bronchial tubes. Mucus and cilia keep the lungs clean by catching dirt particles and sweeping them up the trachea.

When air reaches the lungs, oxygen is diffused into the bloodstream through the alveoli and carbon dioxide is diffused from the blood into the lungs to be exhaled. Diffusion of gases occurs because of differing pressures in the lungs and blood. This is also the same when oxygen diffuses into tissue around the body. When blood has been oxygenated by the lungs, it is transferred around the body to where it is most needed in the bloodstream. If the body is exercising, breathing rate increases and consequently so does heart rate to ensure that oxygen reaches tissues that need it. Oxygen is then used to break down glucose to provide energy for the body. This happens in the mitochondria of cells. Carbon dioxide is one of the waste products of this process, which is why we get a build-up of this gas in our body that needs to be transported back into the lungs to be exhaled.

The body can also respire anaerobically, but this produces far less energy and, instead of producing CO_2 as a byproduct, lactic acid is produced. The body then takes a little time to break this down after exertion has finished, as the body has a so-called oxygen debt.



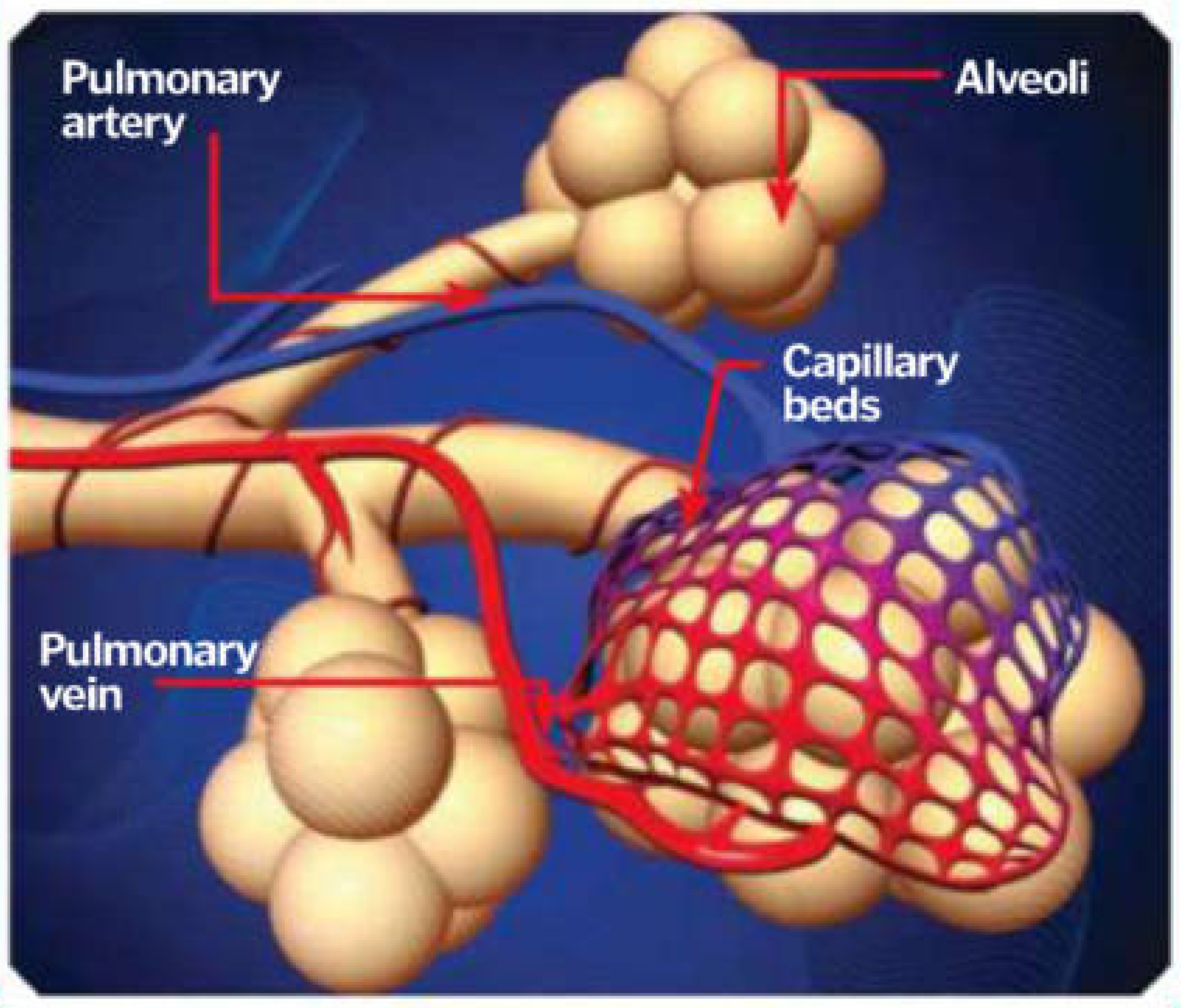
Nasal passage/oral cavity
These areas are where air enters into the body so that oxygen can be transported into and around the body to where it's needed. Carbon dioxide also exits through these areas.

Alveoli
The alveoli are tiny little sacs which are situated at the end of tubes inside the lungs and are in direct contact with blood. Oxygen and carbon dioxide transfer to and from the blood stream through the alveoli.

Bronchial tubes
These tubes lead to either the left or the right lung. Air passes through these tubes into the lungs, where they pass through progressively smaller and smaller tubes until they reach the alveoli.

How our lungs work

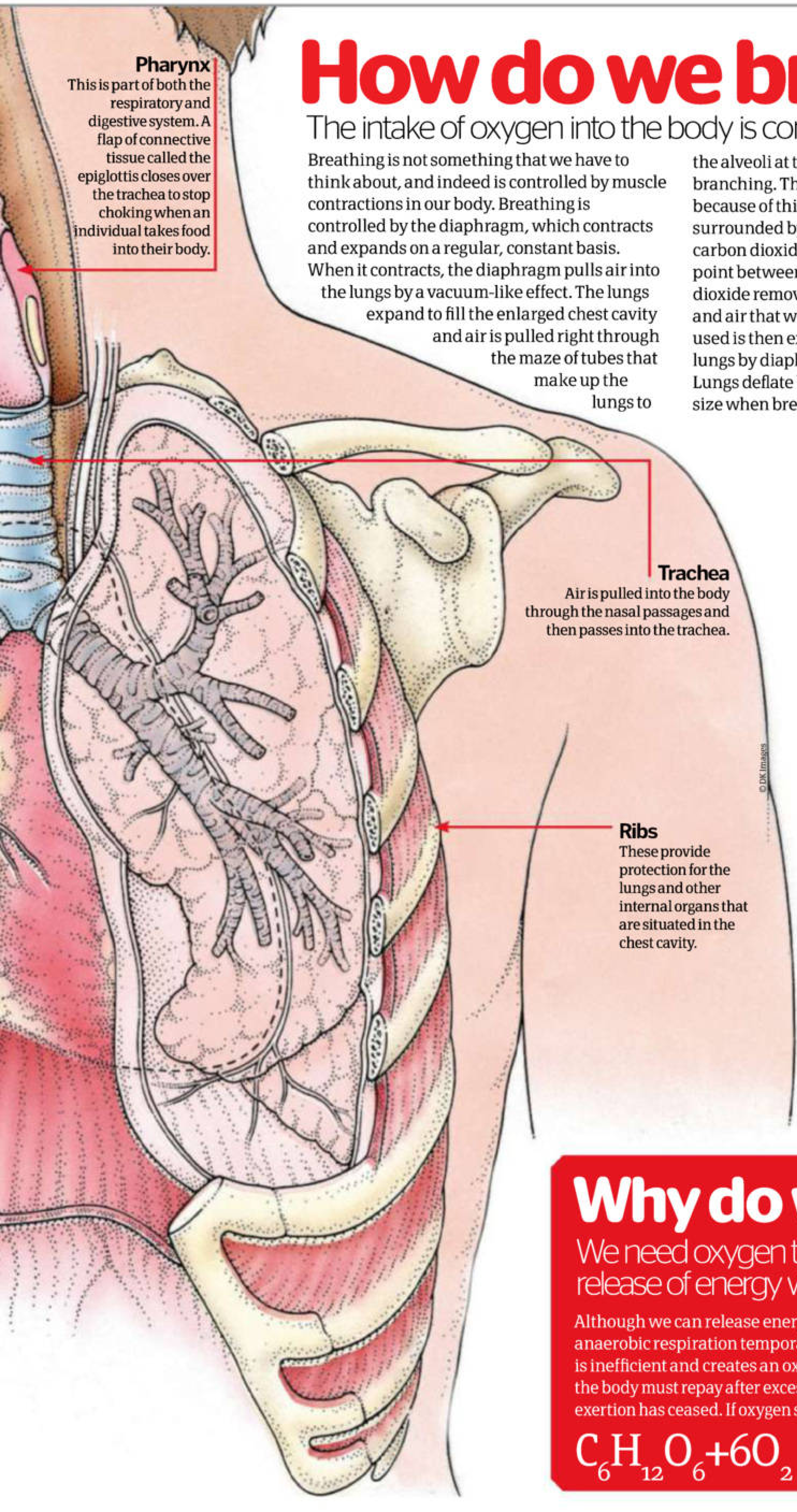
Lungs are the major respiratory organ in humans



How do we breathe?

The intake of oxygen into the body is complex

Breathing is not something that we have to think about, and indeed is controlled by muscle contractions in our body. Breathing is controlled by the diaphragm, which contracts and expands on a regular, constant basis. When it contracts, the diaphragm pulls air into the lungs by a vacuum-like effect. The lungs expand to fill the enlarged chest cavity and air is pulled right through the maze of tubes that make up the lungs to the alveoli at the ends, which are the final branching. The chest will be seen to rise because of this lung expansion. Alveoli are surrounded by blood vessels, and oxygen and carbon dioxide are then interchanged at this point between the lungs and the blood. Carbon dioxide removed from the blood stream and air that was breathed in but not used is then expelled from the lungs by diaphragm expansion. Lungs deflate back to a reduced size when breathing out.



Pharynx
This is part of both the respiratory and digestive system. A flap of connective tissue called the epiglottis closes over the trachea to stop choking when an individual takes food into their body.

Trachea
Air is pulled into the body through the nasal passages and then passes into the trachea.

Ribs
These provide protection for the lungs and other internal organs that are situated in the chest cavity.

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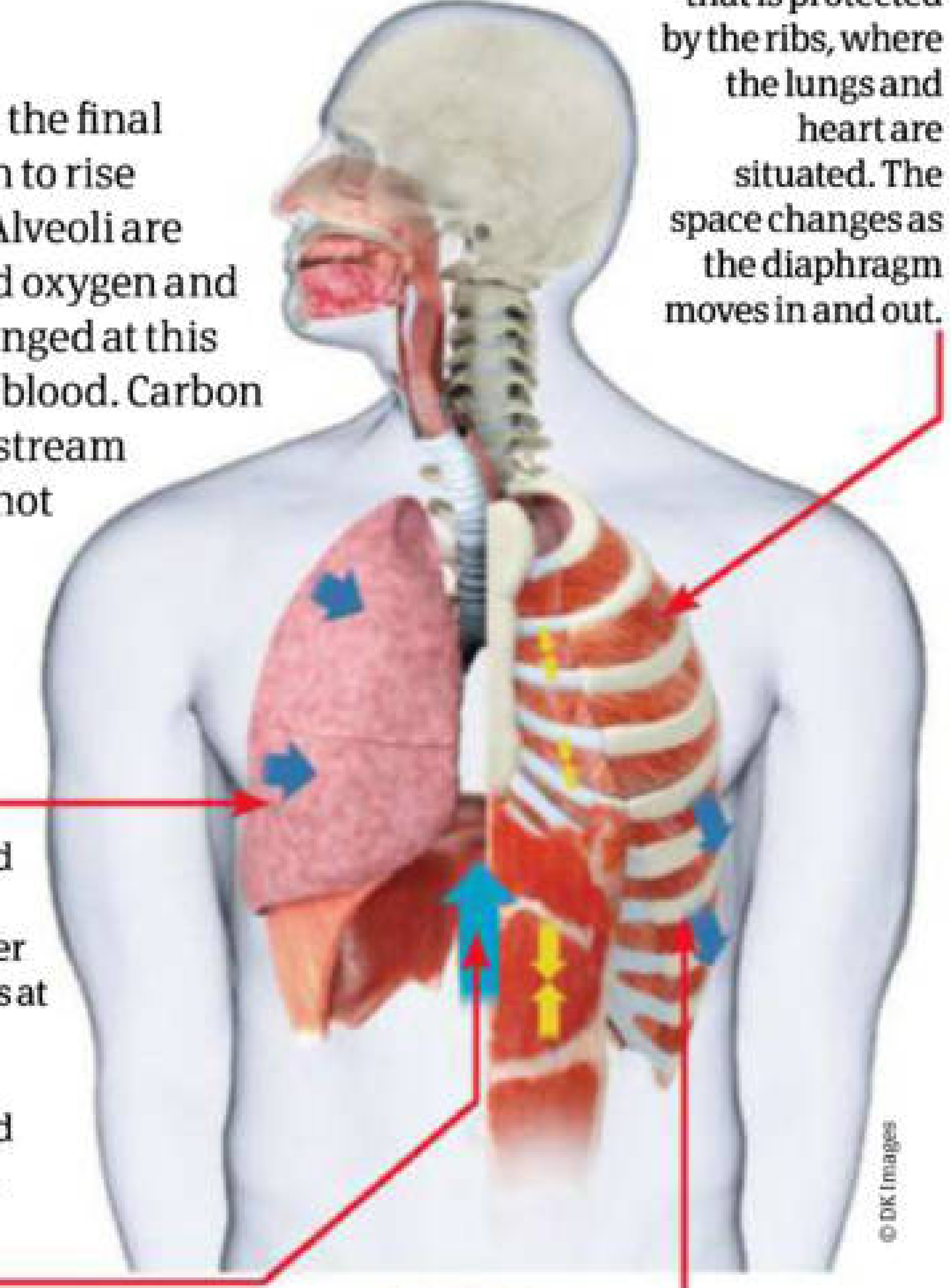

Chest cavity
This is the space that is protected by the ribs, where the lungs and heart are situated. The space changes as the diaphragm moves in and out.

Lungs
Deoxygenated blood arrives back at the lungs, where another gas exchange occurs at the alveoli. Carbon dioxide is removed and oxygen is placed back into the blood.

Diaphragm
This is a sheet of muscle situated at the bottom of the rib cage which contracts and expands to draw air into the lungs.

Rib cage
This is the bone structure which protects the organs. The rib cage can move slightly to allow for lung expansion.

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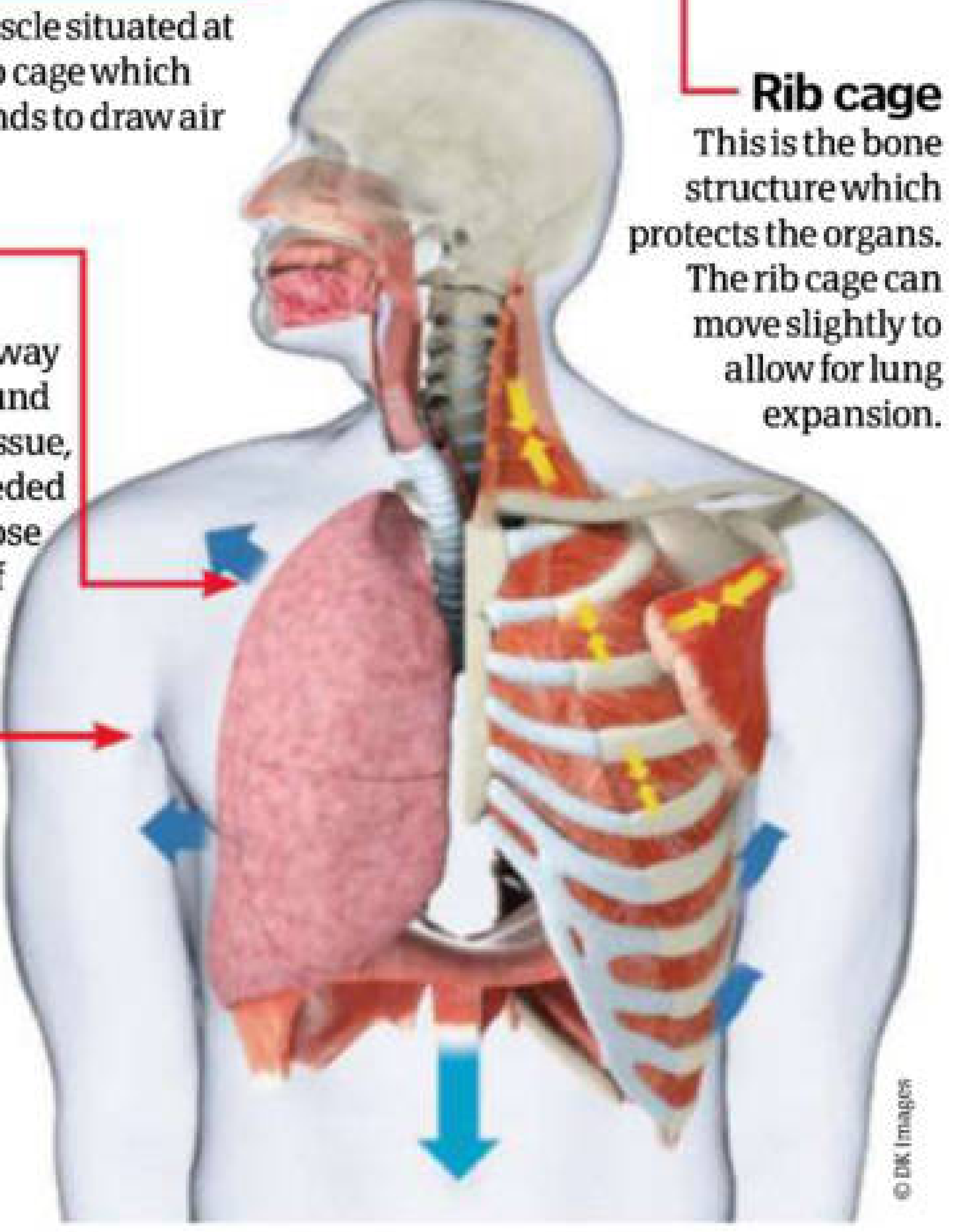

Heart
The heart pumps oxygenated blood away from the lungs, around the body towards tissue, where oxygen is needed to break down glucose into a usable form of energy for the body.

Tissue
Oxygen arrives where energy is needed, and a gas exchange of oxygen and carbon dioxide occurs so that aerobic respiration can occur within cells.

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Why do we need oxygen?

We need oxygen to live as it is crucial for the release of energy within the body

Although we can release energy through anaerobic respiration temporarily, this method is inefficient and creates an oxygen debt that the body must repay after excess exercise or exertion has ceased. If oxygen supply is cut off for more than a few minutes, an individual will die. Oxygen is pumped around the body to be used in cells that need to break down glucose so that energy is provided for the tissue. The equation that illustrates this is:

$$C_6H_{12}O_6+6O_2=6CO_2+6H_2O+\text{energy}$$

A look inside your heart

Your heart is a turbocharged double-pumping muscle that beats more than 40 million times every year

Not only does your heart do amazing things, it does so tirelessly, every minute of every day from the moment you're born (actually, even a bit before then) to the instant that you die. It weighs somewhere between eight and 12 ounces – slightly more if you're male, less if you're female. Its sole purpose is to push blood through your circulatory system, providing crucial oxygen and other nutrients to all your organs.

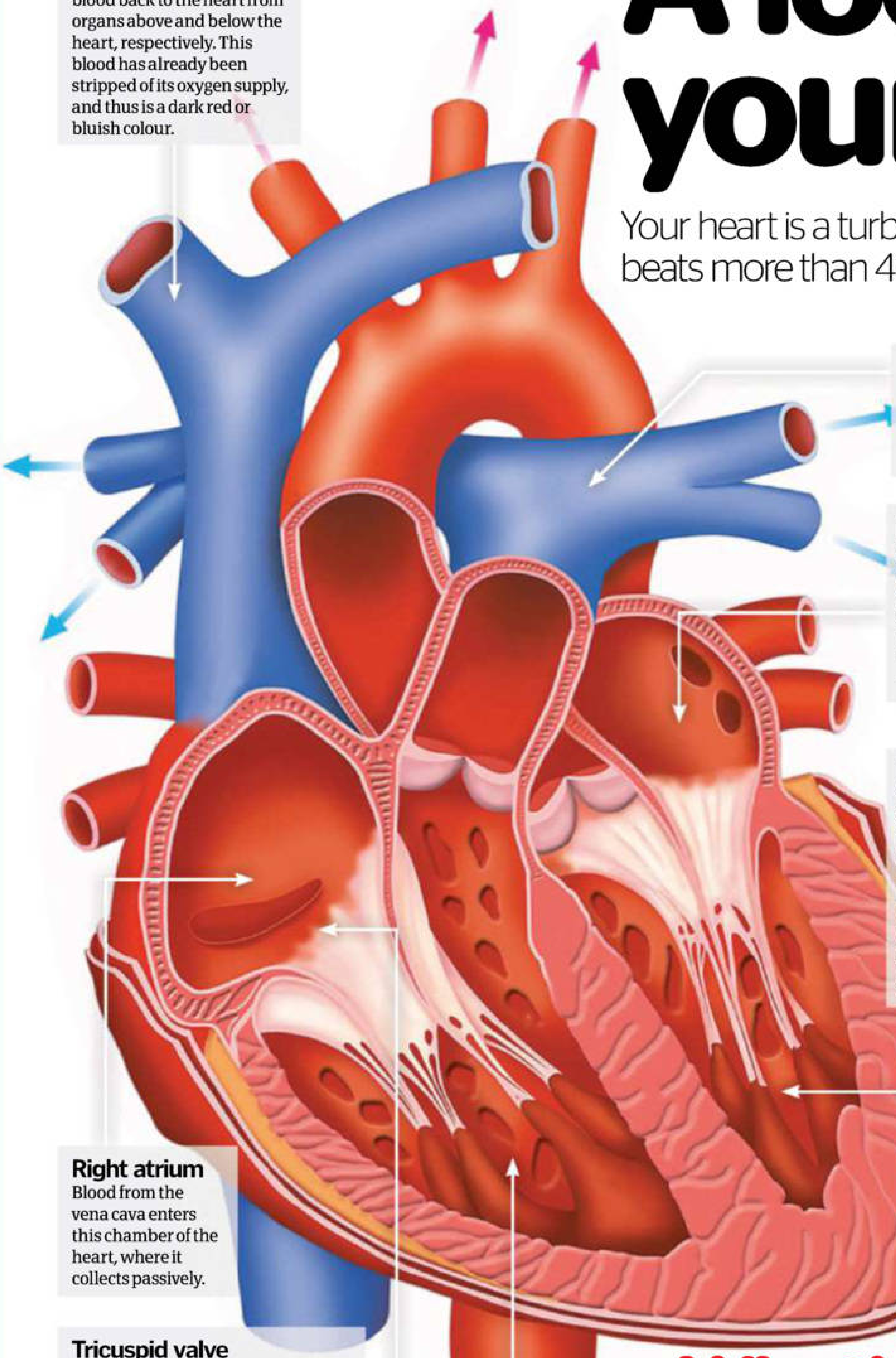
The heart is considered a double pump because the right half sends 'used' blood to your lungs. There, the blood drops off a load of carbon dioxide and picks up some fresh oxygen, which you have helpfully provided by breathing. Then the oxygenated blood returns to the left half of the heart. This 'heart-to-lungs-to-heart-again' trip is known as pulmonary circulation. The left side of the heart then pumps this oxygenated blood to every organ in your body other than your lungs. Your brain, your skin, the muscles in your thigh, your spleen – they all get blood (and therefore oxygen) by virtue of your beating heart.

Even the heart itself gets blood, via a special set of veins and arteries known as the coronary system. The myocardial muscle within the wall of the heart needs oxygen and other nutrients to keep beating. Unfortunately, the coronary arteries that do this job are very narrow, between 1.7 and 2.2 millimetres in diameter. If they become clogged with cholesterol or other fatty deposits, the heart stops working. This is bad for you.

Of course, the relatively simple concept of the double pump is fairly complex in practice. A series of valves control blood flow to the heart's four chambers, allow for the build-up of enough blood pressure to get the job done, and direct the blood to the correct veins and arteries.

What's inside your heart?

Find out how your heart pumps blood around your body



Superior and inferior vena cava
These large veins carry blood back to the heart from organs above and below the heart, respectively. This blood has already been stripped of its oxygen supply, and thus is a dark red or bluish colour.

Pulmonary veins
After the blood collects oxygen from the lungs, it returns to the heart via the pulmonary veins.

Left atrium
Blood brimming with oxygen and other nutrients collects here. When the atrium contracts, the blood passes through the mitral valve and enters the left ventricle under pressure.

Left ventricle
The left ventricle must send blood on a longer journey than the right ventricle, so it has thicker walls and uses about three times as much energy. Luckily, the left atrium's contraction gives the left ventricle's output an extra 20 per cent boost.

Right atrium
Blood from the vena cava enters this chamber of the heart, where it collects passively.

Tricuspid valve
When the right atrium contracts, it pushes blood through the tricuspid valve, a one-way valve leading down into the right ventricle.

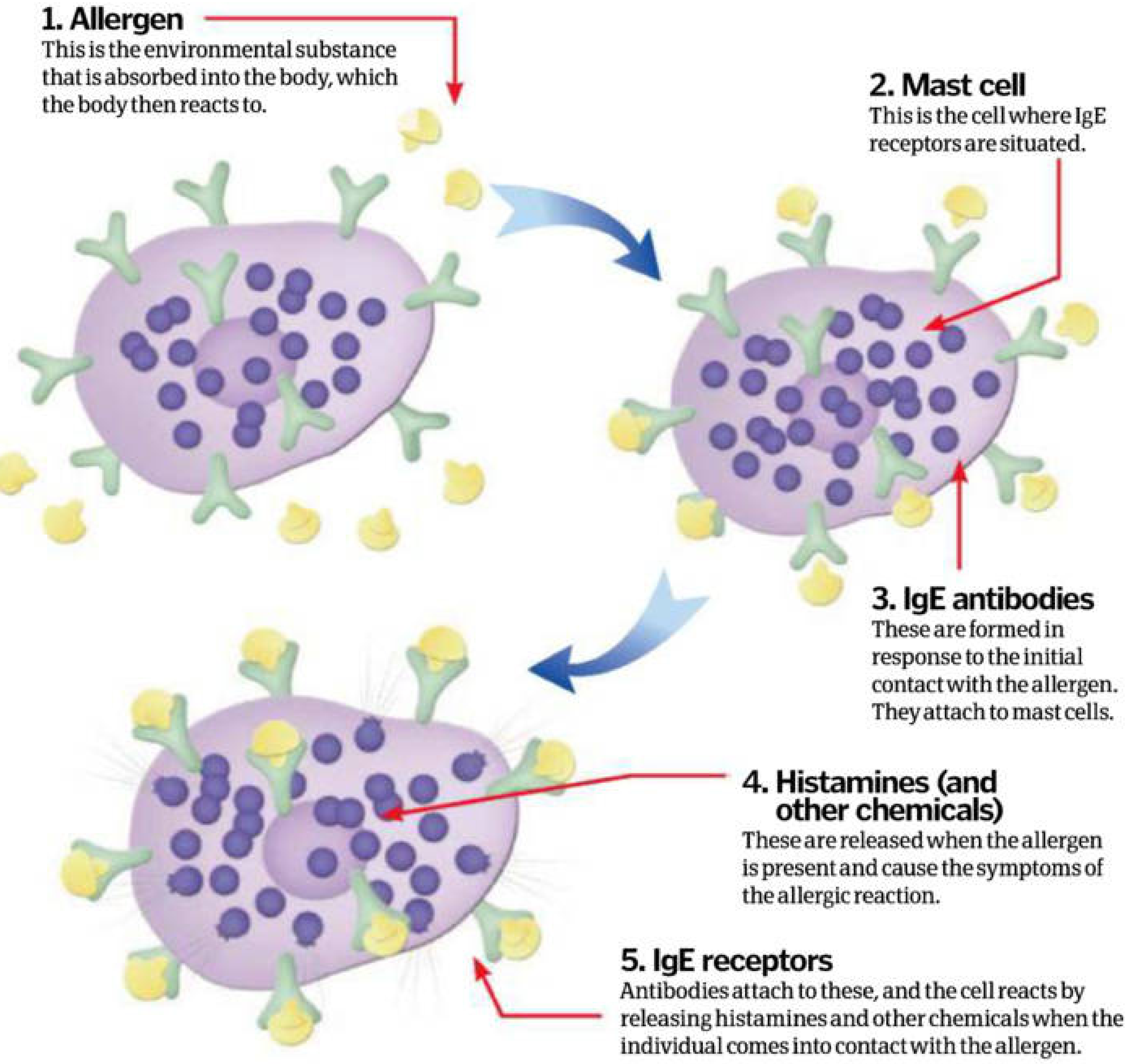
Right ventricle
Blood enters the right ventricle under pressure from the atrium's contraction, giving it a boost much like the turbocharger in a high-performance car. The ventricle contracts and pumps blood through the pulmonary valve, into the pulmonary artery and toward the lungs.

How do allergies affect us?

Hay fever is seen to be becoming more common, but how and why do allergens cause our bodies to react?

Allergic reactions occur in response to specific environmental stimuli (called allergens), such as pollen, dust, bee stings and food, and the reaction displayed in individuals is normally due to an immune system disorder. Most allergies are mild, but some can be severe and even fatal depending on the reaction and treatment received following exposure to the allergen.

Allergies are actually caused by the immune system being hypersensitive to elements within the environment, rather than – as many people suppose – it being under active. Large numbers of antibodies are produced in response to the allergen, which then cause an over-reaction in the immune system when the individual next comes into contact with the allergen – so creating the allergic reaction.



1. Allergen
This is the environmental substance that is absorbed into the body, which the body then reacts to.

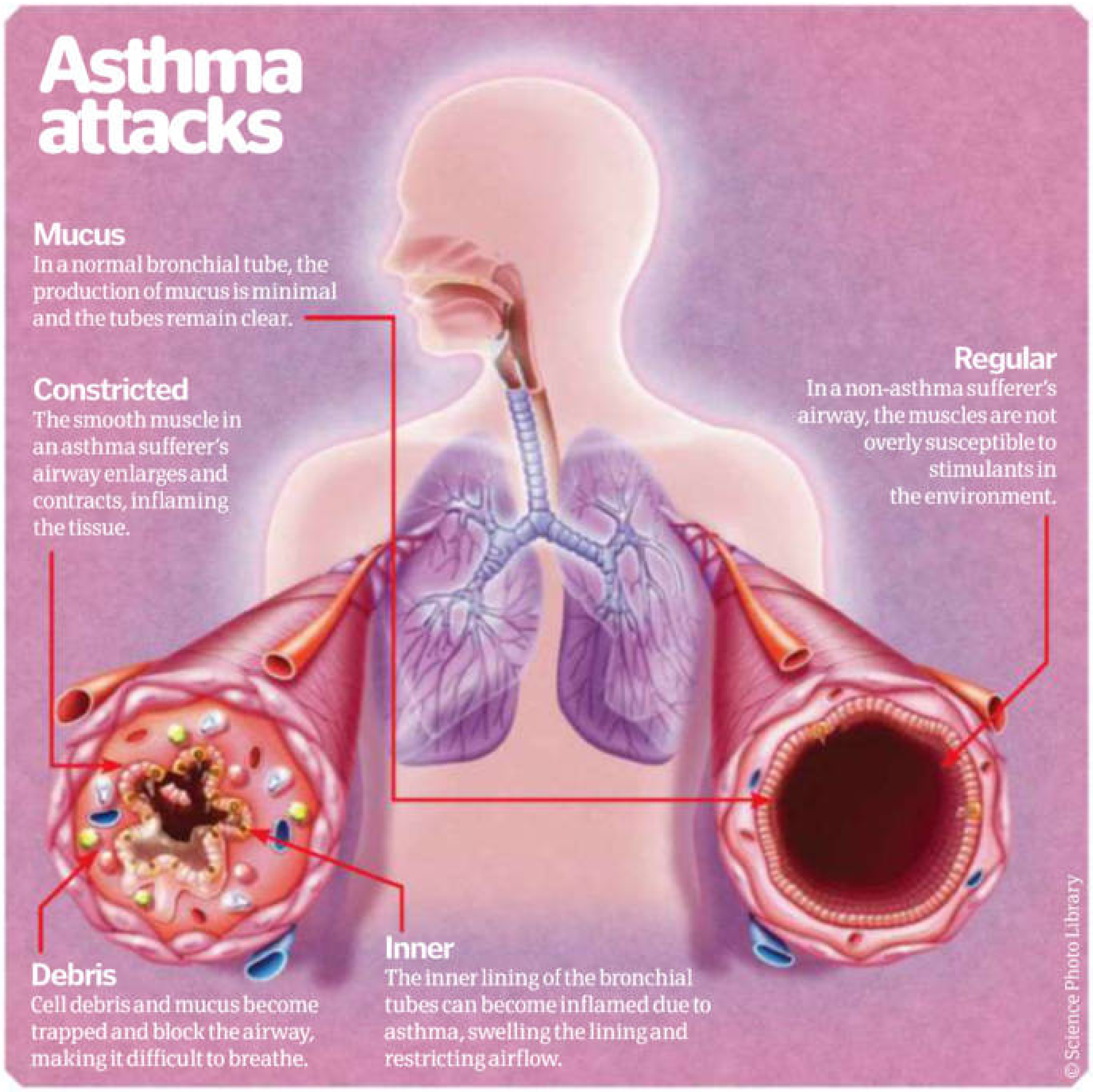
2. Mast cell
This is the cell where IgE receptors are situated.

3. IgE antibodies
These are formed in response to the initial contact with the allergen. They attach to mast cells.

4. Histamines (and other chemicals)
These are released when the allergen is present and cause the symptoms of the allergic reaction.

5. IgE receptors
Antibodies attach to these, and the cell reacts by releasing histamines and other chemicals when the individual comes into contact with the allergen.

Asthma attacks



Mucus
In a normal bronchial tube, the production of mucus is minimal and the tubes remain clear.

Constricted
The smooth muscle in an asthma sufferer's airway enlarges and contracts, inflaming the tissue.

Regular
In a non-asthma sufferer's airway, the muscles are not overly susceptible to stimulants in the environment.

Debris
Cell debris and mucus become trapped and block the airway, making it difficult to breathe.

Inner
The inner lining of the bronchial tubes can become inflamed due to asthma, swelling the lining and restricting airflow.

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Asthma

Why does this disease make it difficult for sufferers to breathe?

Asthma is caused by the sudden contraction of smooth muscles in the airways of the body. This is normally due to unusually viscous mucus being produced in abundance in the bronchial mucous glands. One of the primary causes of asthma is the narrowing of bronchial tubes because of inflammation. Asthmatics are overly sensitive (hyperreactive) to stimulants in the environment that can cause the bronchial muscles and tubes to contract. Tubes become irritated and swollen, in turn producing excess mucus and blocking the flow of air. While asthma is often hereditary, it can also be acquired through prolonged exposure to substances such as solder and sulphite.

In severe asthma attacks, the accumulation of additional mucus from the bronchial tree can also inhibit airflow within the airways, making it more difficult for an asthma sufferer to breathe. There are several things that can trigger an asthma attack, including exercising, animal hairs and traffic fumes. To overcome an attack, an asthma inhaler can be used to relax the muscles and widen the bronchial tubes so that normal breathing can be resumed.

Kidney function

How do your kidneys filter waste from the blood to keep you alive?

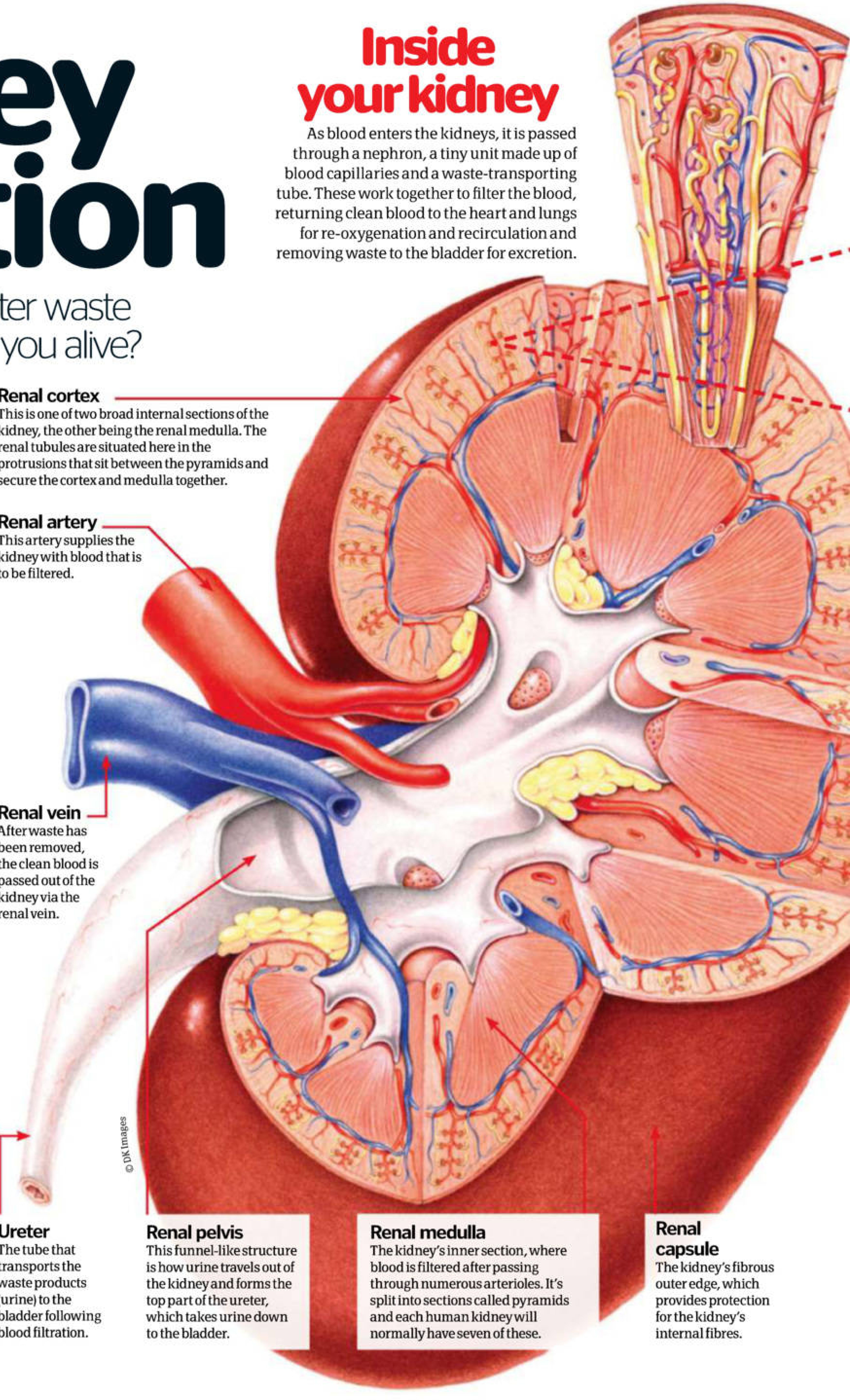
Kidneys are bean-shaped organs situated halfway down the back just under the ribcage, one on each side of the body, and weigh between 115 and 170 grams each, dependent on the individual's sex and size. The left kidney is commonly a little larger than the one on the right and, due to the effectiveness of these organs, individuals born with only one kidney can survive with little or no adverse health problems. Indeed, the body can operate normally with a 30-40 per cent decline in kidney function. This decline in function would rarely even be noticeable and shows just how effective the kidneys are at filtering out waste products as well as maintaining mineral levels and blood pressure throughout the body. The kidneys manage to control all of this by working with other organs and glands across the body such as the hypothalamus, which helps the kidneys to determine and then control water levels in the body.

Each day the kidneys will filter between 150 and 180 litres of blood, but only pass around two litres of waste down the ureters to the bladder for excretion. This waste product is primarily urea – a by-product of protein being broken down for energy – and water, and it's more commonly known as 'urine'. The kidneys filter the blood by passing it through a small filtering unit called a nephron. Each kidney has around a million of these, which are made up of a number of small blood capillaries, called glomerulus, and a urine-collecting tube called the renal tubule. The glomerulus sift the normal cells and proteins from the blood and then move the waste products into the renal tubule, which transports urine down into the bladder through the ureters.

Alongside this filtering process, the kidneys also release three crucial hormones (known as erythropoietin, renin and calcitriol) which encourage red blood cell production, aid regulation of blood pressure and aid bone development and mineral balance respectively.

Inside your kidney

As blood enters the kidneys, it is passed through a nephron, a tiny unit made up of blood capillaries and a waste-transporting tube. These work together to filter the blood, returning clean blood to the heart and lungs for re-oxygenation and recirculation and removing waste to the bladder for excretion.



Renal cortex
This is one of two broad internal sections of the kidney, the other being the renal medulla. The renal tubules are situated here in the protrusions that sit between the pyramids and secure the cortex and medulla together.

Renal artery
This artery supplies the kidney with blood that is to be filtered.

Renal vein
After waste has been removed, the clean blood is passed out of the kidney via the renal vein.

Ureter
The tube that transports the waste products (urine) to the bladder following blood filtration.

Renal pelvis
This funnel-like structure is how urine travels out of the kidney and forms the top part of the ureter, which takes urine down to the bladder.

Renal medulla
The kidney's inner section, where blood is filtered after passing through numerous arterioles. It's split into sections called pyramids and each human kidney will normally have seven of these.

Renal capsule
The kidney's fibrous outer edge, which provides protection for the kidney's internal fibres.

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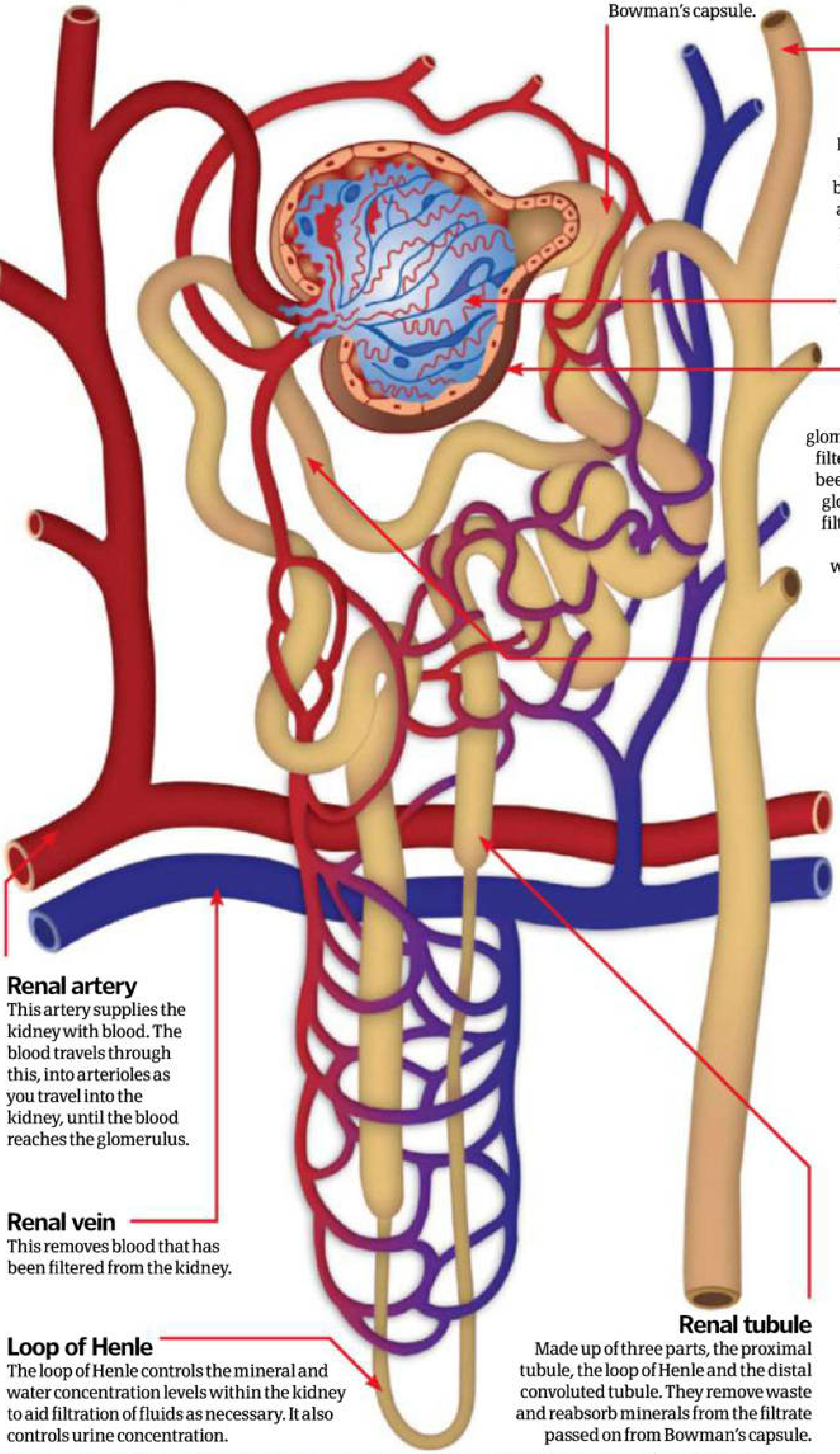
Nephrons – the filtration units of the kidney

Nephrons are the units which filter all blood that passes through the kidneys. There are around a million in each kidney, situated in the renal medulla's pyramid structures. As well as filtering waste, nephrons regulate water and mineral salt by recirculating what is needed and excreting the rest.



Proximal tubule
This links Bowman's capsule and the loop of Henle, and will selectively reabsorb minerals from the filtrate produced by Bowman's capsule.

Collecting duct system
Although not technically part of the nephron, this collects all waste product filtered by the nephrons and facilitates its removal from the kidneys.

Glomerulus
High pressure in the glomerulus, caused by it draining into an arteriole instead of a venule, forces fluids and soluble materials out of the capillary and into Bowman's capsule.

Bowman's capsule
Also known as the glomerular capsule, this filters the fluid that has been expelled from the glomerulus. Resulting filtrate is passed along the nephron and will eventually make up urine.

Distal convoluted tubule
Partly responsible for the regulation of minerals in the blood, linking to the collecting duct system. Unwanted minerals are excreted from the nephron.

Renal artery
This artery supplies the kidney with blood. The blood travels through this, into arterioles as you travel into the kidney, until the blood reaches the glomerulus.

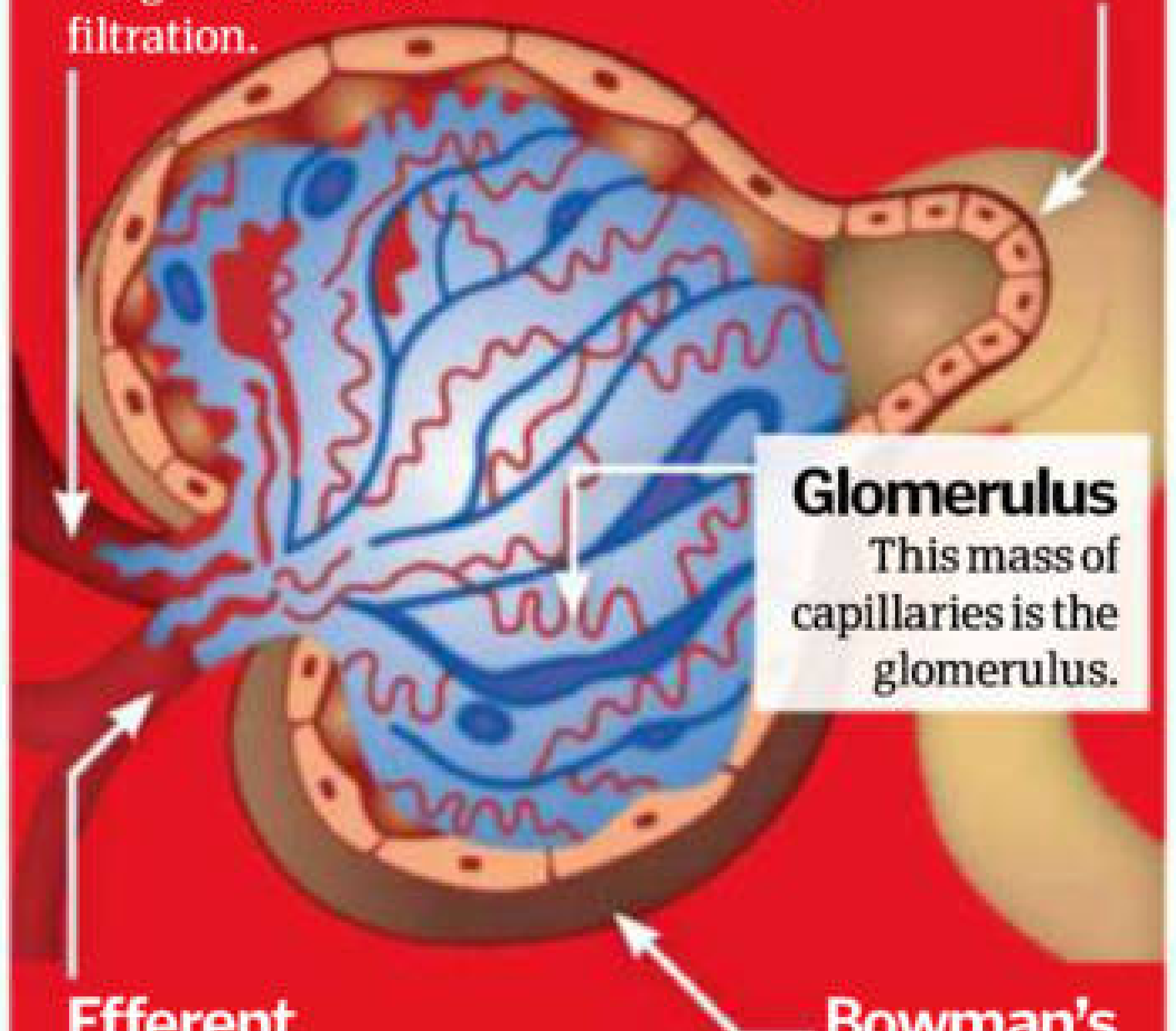
Renal vein
This removes blood that has been filtered from the kidney.

Loop of Henle
The loop of Henle controls the mineral and water concentration levels within the kidney to aid filtration of fluids as necessary. It also controls urine concentration.

Renal tubule
Made up of three parts, the proximal tubule, the loop of Henle and the distal convoluted tubule. They remove waste and reabsorb minerals from the filtrate passed on from Bowman's capsule.

The glomerulus

This group of capillaries is the first step of filtration and a crucial aspect of a nephron. As blood enters the kidneys via the renal artery, it is passed down through a series of arterioles which eventually lead to the glomerulus. This is unusual, as instead of draining into a venule (which would lead back to a vein) it drains back into an arteriole, which creates much higher pressure than normally seen in capillaries, which in turn forces soluble materials and fluids out of the capillaries. This process is known as ultrafiltration and is the first step in filtration of the blood. These then pass through the Bowman's capsule (also know as the glomerular capsule) for further filtration.



Afferent arteriole
This arteriole supplies the blood to the glomerulus for filtration.

Proximal tubule
Where reabsorption of minerals from the filtrate from Bowman's capsule will occur.

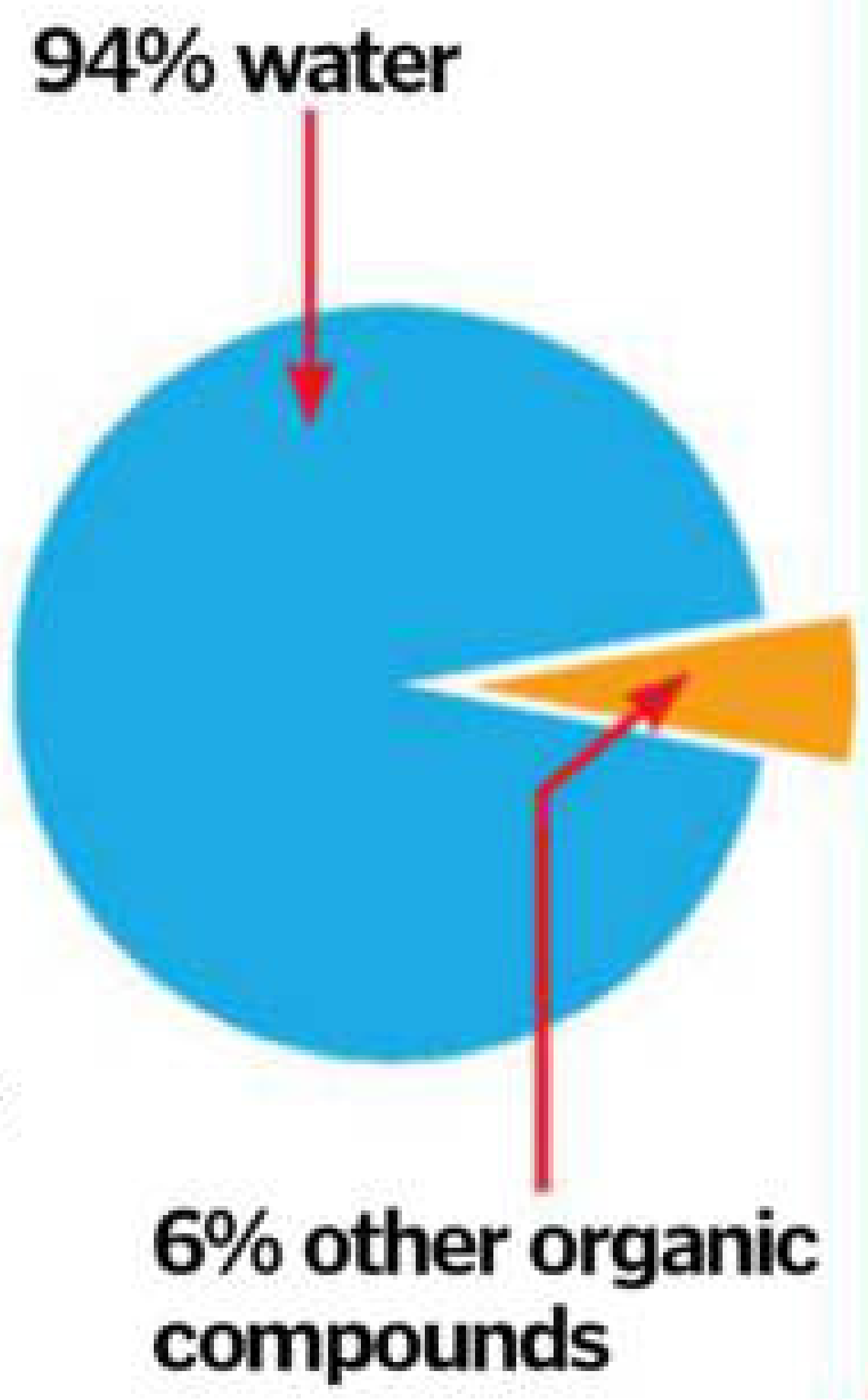
Glomerulus
This mass of capillaries is the first step of filtration and is the glomerulus.

Efferent arteriole
This arteriole is how blood leaves the glomerulus following ultrafiltration.

Bowman's capsule
This is the surrounding capsule that will filter the filtrate produced by the glomerulus.

What is urine and what is it made of?

Urine is made up of a range of organic compounds such as proteins and hormones, inorganic salts and numerous metabolites. These by-products are often rich in nitrogen and need to be removed from the blood stream through urination. The pH-level of urine is typically around neutral (pH7) but varies depending on diet, hydration levels and physical fitness. The colour of urine is also determined by these factors, with dark-yellow urine indicating dehydration and greenish urine being indicative of excessive asparagus consumption.



How the liver works

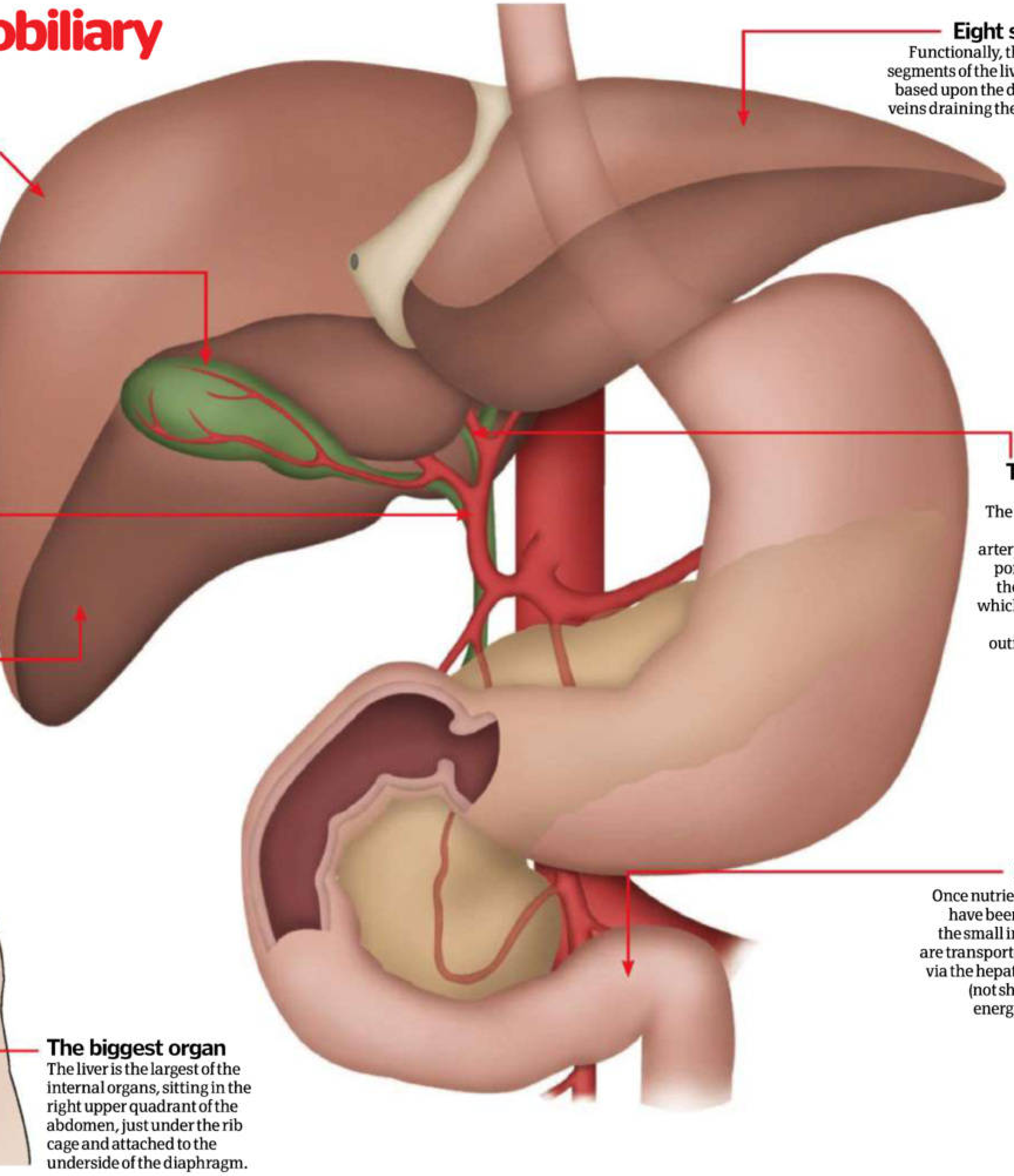
The human liver is the ultimate multitasker – it performs many different functions all at the same time without you even asking

The liver is the largest internal organ in the human body and amazingly has over 500 different functions. In fact, it is the second most complex organ after the brain and is intrinsically involved in almost every aspect of the body's metabolic processes. The liver's main functions are energy production, removal of harmful substances and the production of crucial proteins. These tasks are carried out within liver cells, called hepatocytes, which sit in complex arrangements in order to maximise their efficiency.

The liver is the body's main powerhouse, producing and storing glucose as a key energy source. It is also responsible for breaking down complex fat molecules and building them up into cholesterol and triglycerides, which the body needs but which are bad in excess. The liver makes many complex proteins, including clotting factors which are vital in arresting bleeding. Bile, which helps digest fat in the intestines, is produced in the liver and stored in the adjacent gallbladder.

The liver also plays a key role in detoxifying the blood. Waste products, toxins and drugs are processed here into

The hepatobiliary region



Two halves
The liver is anatomically split into two halves: left and right. There are four lobes, and the right lobe is the largest.

The gallbladder
The gallbladder and liver are intimately related. Bile, which helps digest fat, is produced in the liver and stored in the gallbladder.

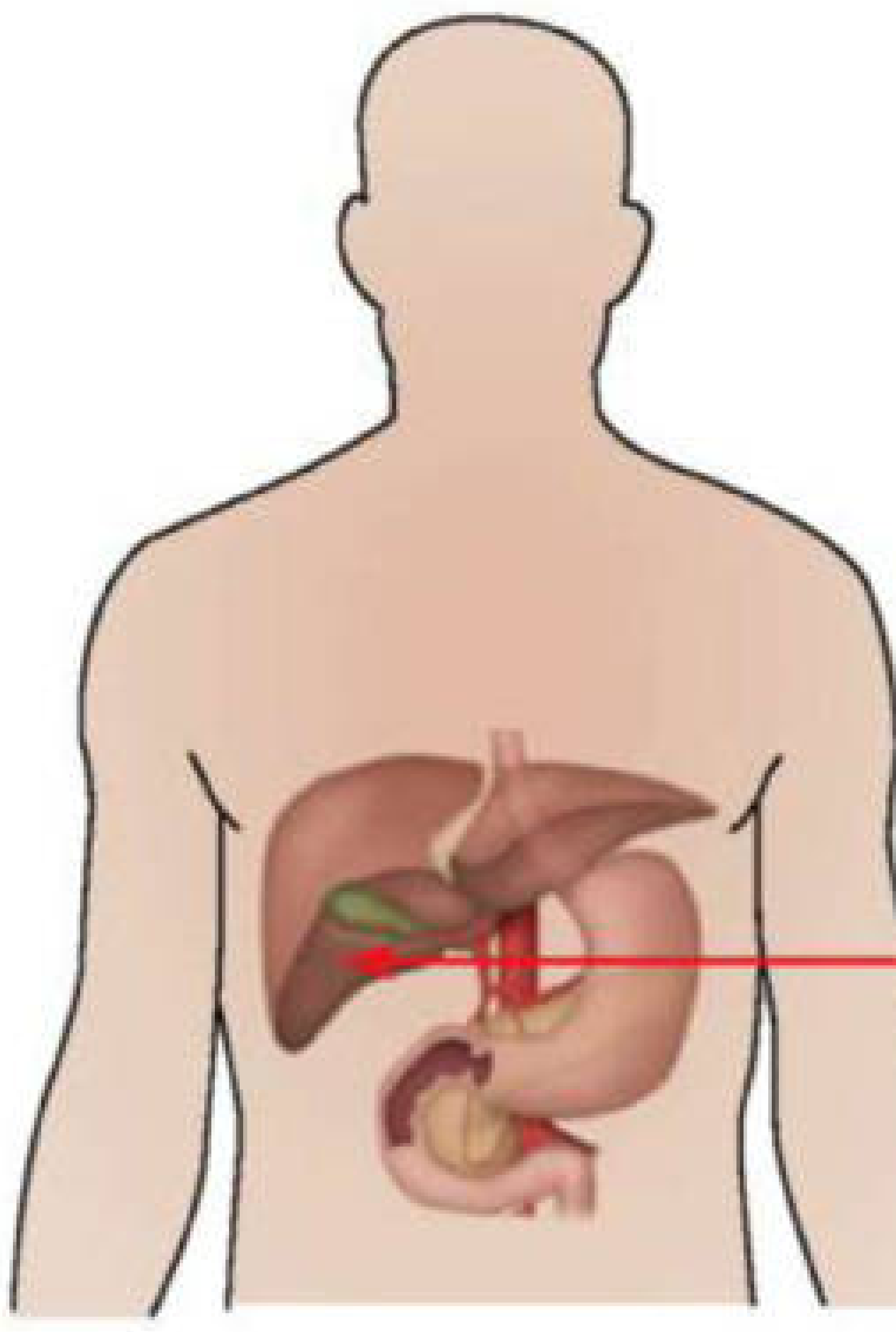
The common bile duct
This duct is small, but vital in the human body. It carries bile from the liver and gallbladder into the duodenum where it helps digest fat.

Feel your liver
Take a deep breath in and feel just under the right lower edge of your ribs – in some people the lower edge of the liver can be felt.

Eight segments
Functionally, there are eight segments of the liver, which are based upon the distribution of veins draining these segments.

The portal triad
The common bile duct, hepatic artery and hepatic portal vein form the portal triad, which are the vital inflows and outflows for your body's liver.

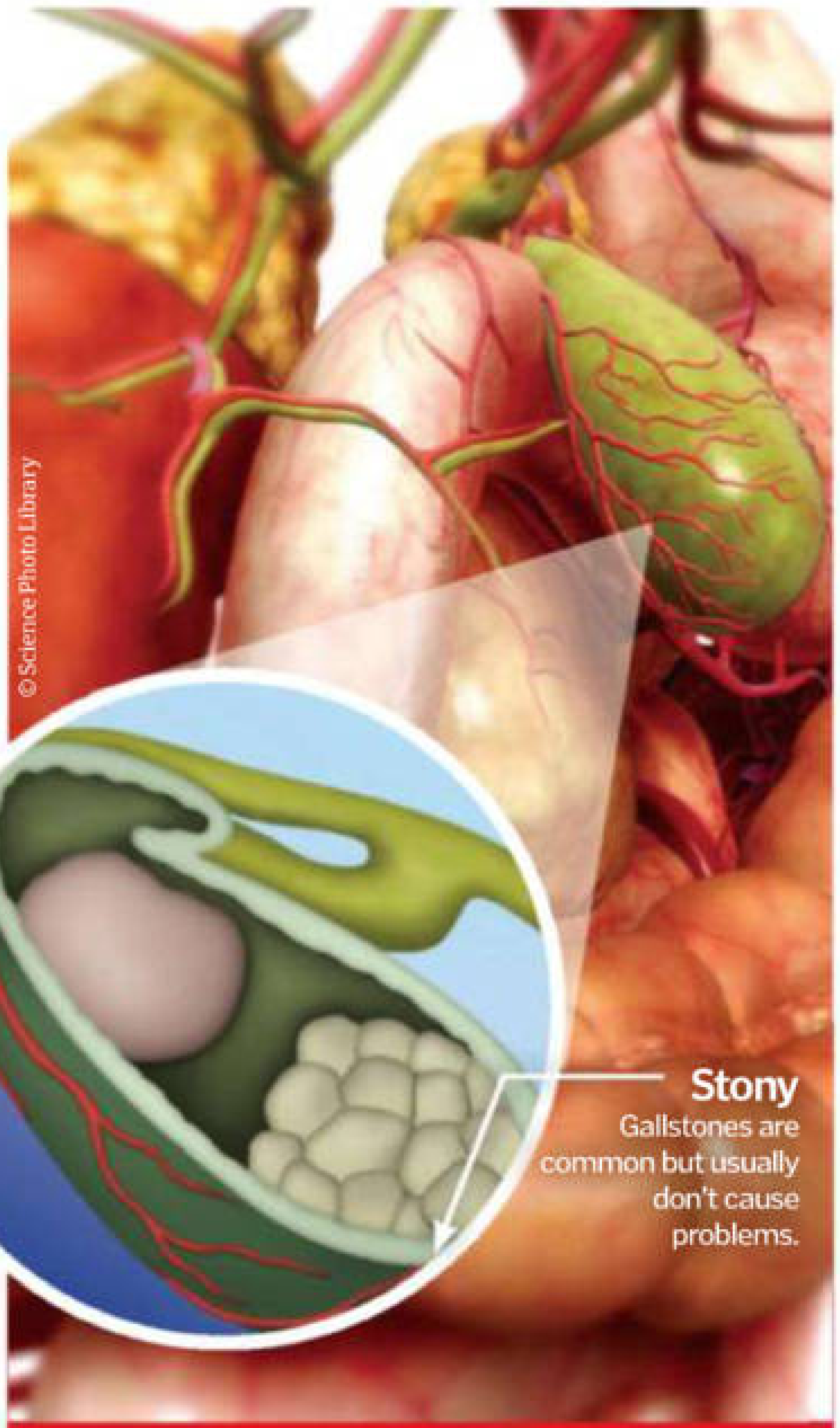
Digestion
Once nutrients from food have been absorbed in the small intestine, they are transported to the liver via the hepatic portal vein (not shown here) for energy production.



The biggest organ
The liver is the largest of the internal organs, sitting in the right upper quadrant of the abdomen, just under the rib cage and attached to the underside of the diaphragm.

forms which are easier for the rest of the body to use or excrete. The liver also breaks down old bloods cells, produces antibodies to fight infection and recycles hormones such as adrenaline. Numerous essential vitamins and minerals are stored in the liver too: vitamins A, D, E and K, plus iron and copper.

Such a complex organ is also unfortunately prone to diseases. Cancers (most often metastatic from other sources), infections (hepatitis) and cirrhosis (a form of fibrosis often caused by excess alcohol consumption) are just some of those which can affect the liver.



Stony
Gallstones are common but usually don't cause problems.

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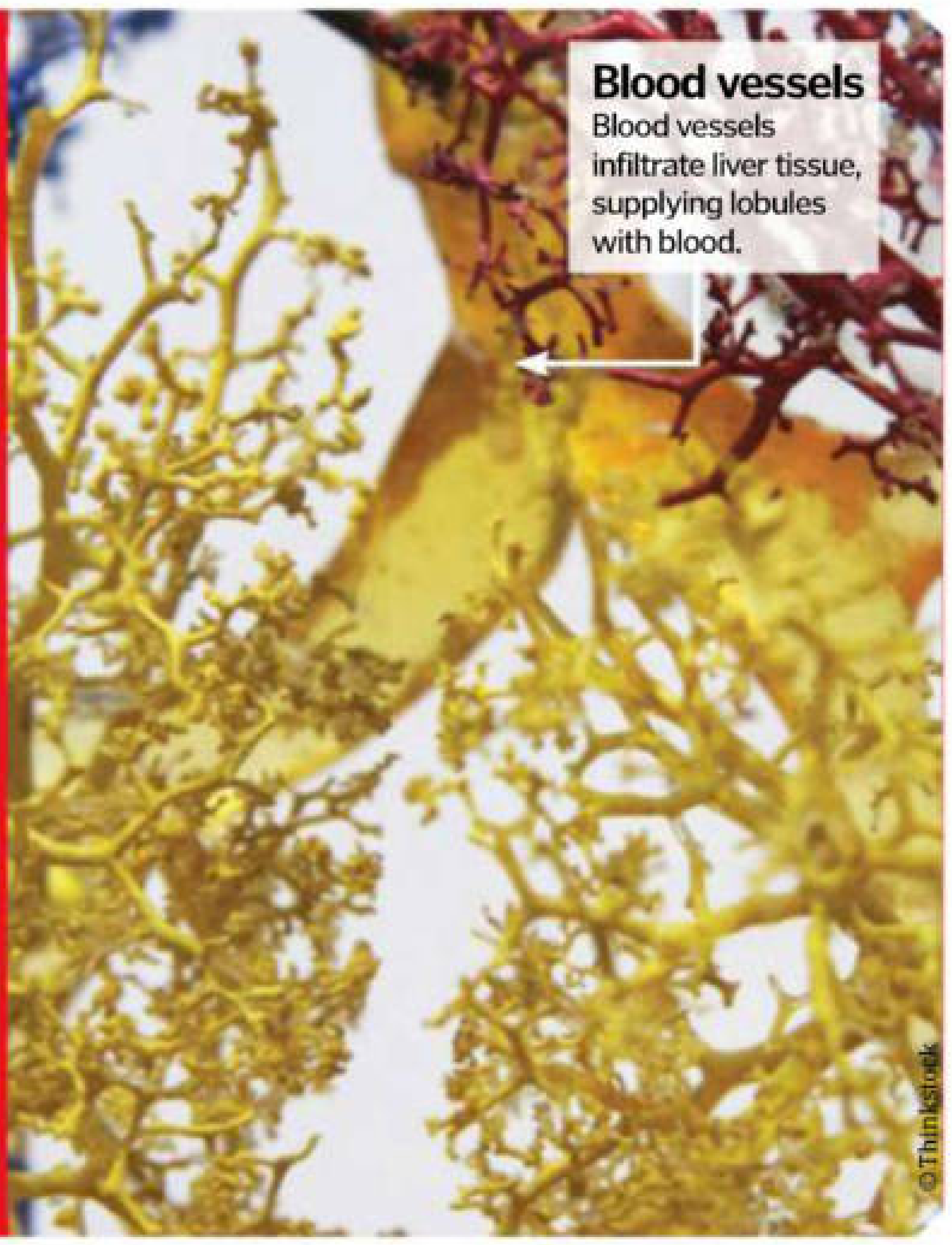
The gallbladder

Bile, a dark green slimy liquid, is produced in the hepatocytes and helps to digest fat. It is stored in a reservoir which sits on the under-surface of the liver, to be used when needed. This reservoir is called the gallbladder. Stones can form in the gallbladder (gallstones) and are very common, although most don't cause problems. In 2009, just under 60,000 gallbladders were removed from patients within the NHS, making it one of the most common operations performed; over 90 per cent of these are removed via keyhole surgery. Most patients do very well without their gallbladder and don't notice any changes at all.

A high demand organ

The liver deals with a massive amount of blood. It is unique because it has two blood supplies. 75 per cent of this comes directly from the intestines (via the hepatic portal vein) which carries nutrients from digestion, which the liver processes and turns into energy. The rest comes from the heart, via the hepatic artery (which branches from the aorta), carrying oxygen which the liver needs to produce this energy. The blood flows in tiny passages inbetween the liver cells where the many metabolic functions occur. The blood then leaves the liver via the hepatic veins to flow into the biggest vein in the body – the inferior vena cava.



Blood vessels
Blood vessels infiltrate liver tissue, supplying lobules with blood.

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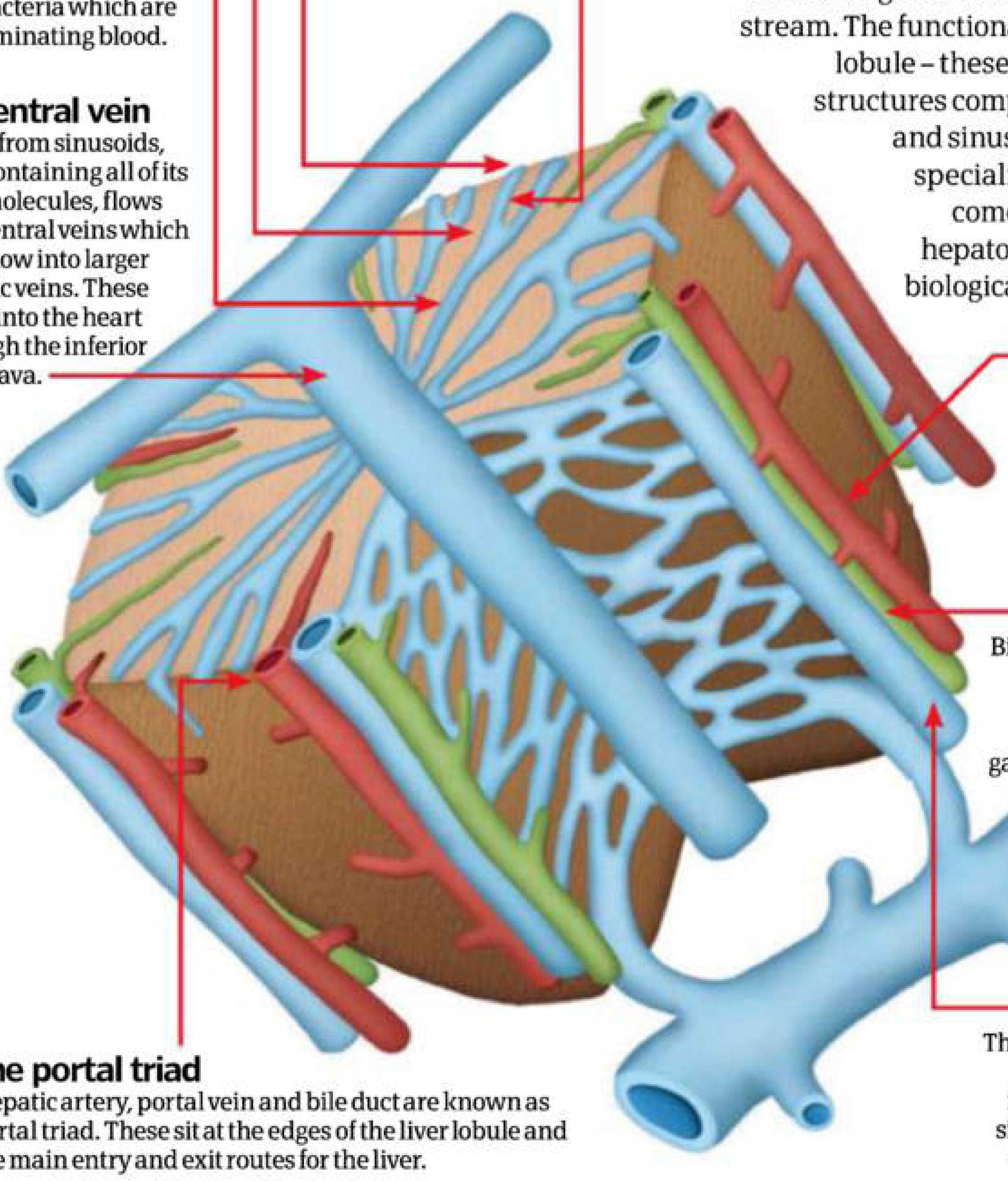
Liver lobules

The functional unit which performs the liver's tasks

The liver is considered a 'chemical factory,' as it forms large complex molecules from smaller ones brought to it from the gut via the blood stream. The functional unit of the liver is the lobule – these are hexagonal-shaped structures comprising of blood vessels and sinusoids. Sinusoids are the specialised areas where blood comes into contact with the hepatocytes, where the liver's biological processes take place.



1. The lobule
This arrangement of blood vessels, bile ducts and hepatocytes form the functional unit of the liver.

2. The hepatocyte
These highly active cells perform all of the liver's key metabolic tasks.

3. Sinusoids
These blood-filled channels are lined by hepatocytes and provide the site of transfer of molecules between blood and liver cells.

4. Kupffer cells
These specialised cells sit within the sinusoids and destroy any bacteria which are contaminating blood.

5. Hepatic artery branch
Blood from here supplies oxygen to hepatocytes and carries metabolic waste which the liver extracts.

6. Bile duct
Bile, which helps digest fat, is made in hepatocytes and secreted into bile ducts. It then flows into the gallbladder for storage before being secreted into the duodenum.

7. Portal vein
This vein carries nutrient-rich blood directly from the intestines, which flows into sinusoids for conversion into energy within hepatocytes.

8. The portal triad
The hepatic artery, portal vein and bile duct are known as the portal triad. These sit at the edges of the liver lobule and are the main entry and exit routes for the liver.

9. Central vein
Blood from sinusoids, now containing all of its new molecules, flows into central veins which then flow into larger hepatic veins. These drain into the heart through the inferior vena cava.

The human hand

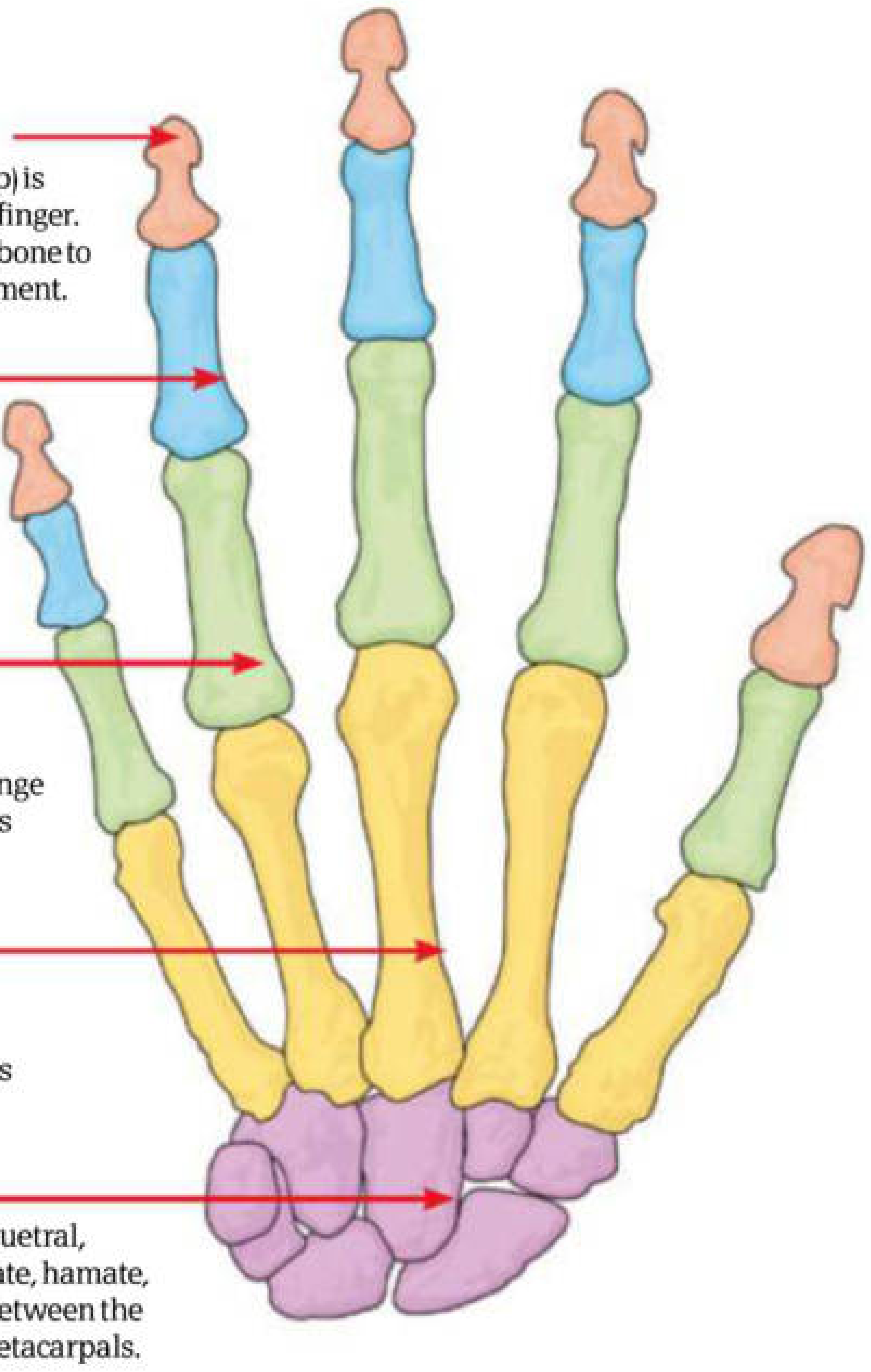
We take our hands for granted, but they are actually quite complex and have been crucial in our evolution

The human hand is an important feature of the human body which allows individuals to manipulate their surroundings and also to gather large amounts of data from the environment that the individual is situated within. A hand is generally defined as the terminal aspect of the human arm, which consists of prehensile digits, an opposable thumb, and a wrist and palm. Although many other animals have similar structures, only primates and a limited number of other vertebrates can be said to have a 'hand' due to the need for an opposable thumb to be present and the degree of extra articulation that the human hand can achieve. Due to this extra articulation, humans have developed fine motor skills allowing for much increased control in this limb. Consequently we see improved ability to grasp and grip items and development of skills such as writing.

A hand is made up of five digits, the palm and wrist. It consists of 27 bones, tendons, muscles and nerves, with each fingertip of each digit containing numerous nerve endings making the hand a crucial area for gathering information from the environment using one of man's most crucial five senses: touch. Muscles interact together with tendons to allow fingers to bend, straighten, point and, in the case of the thumb, rotate. However, the hand is an area that sees many injuries due to the number of ways we use it, one in ten injuries in A&E being hand related, and there are also several disorders that can affect the hand development in the womb, such as polydactyly, where an individual is born with extra digits, which are often in perfect working order.

Bones in the hand

The human hand contains 27 bones, and these divide up into three distinct groups: the carpals, metacarpals and phalanges. These also then further break down into three: the proximal phalanges, intermediate phalanges and distal phalanges. Eight bones are situated in the wrist and these are collectively called the carpals. The metacarpals, which are situated in the palm of the hand account for a further five out of the 27, and each finger has three phalanges, the thumb has two. Intrinsic muscles and tendons interact to control movement of the digits and hand, and attach to extrinsic muscles that extend further up into the arm, which flex the digits.



Distal phalanges
A distal phalange (fingertip) is situated at the end of each finger. Deep flexors attach to this bone to allow for maximum movement.

Intermediate phalanges
This is where the superficial flexors attach via tendons to allow the digit to bend.

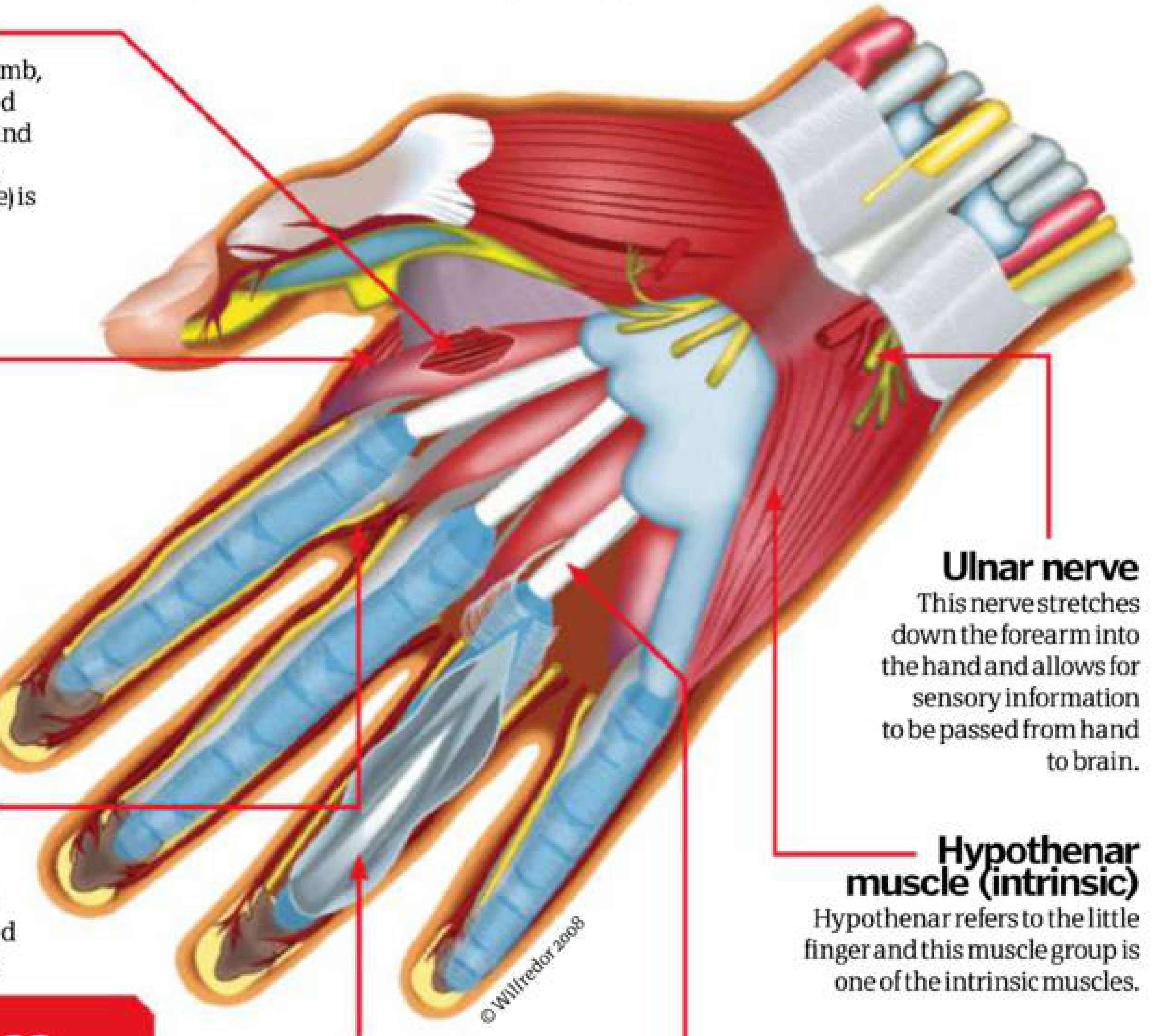
Proximal phalanges
Each finger has three phalanges, and this phalange joins the intermediate to its respective metacarpal.

Metacarpals
These five bones make up the palm, and each one aligns with one of the digits of the hand.

Carpals
The carpals (scaphoid, triquetral, trapezium, trapezoid, lunate, hamate, capitate and pisiform) sit between the ulna and radius and the metacarpals.

Muscles and other structures

The movements and articulations of the hand and by the digits are controlled by tendons and two muscle groups situated within the hand and wrist. These are the extrinsic and intrinsic muscle groups, so named as the extrinsics are attached to muscles which extend into the forearm, whereas the intrinsics are situated within the hand and wrist. The flexors and extensors, which make up the extrinsic muscles, use either exclusively tendons to attach to digits they control (flexors) or a more complex mix of tendons and intrinsic muscles to operate (extensors). These muscles will contract in order to cause digit movement, and flexors and extensors work in a pair to complement each to straighten and bend digits. The intrinsic muscles are responsible for aiding extrinsic muscle action and other movements in the digits and have three distinct groups; the thenar and hypothenar (referring to the thumb and little finger respectively), the interossei and the lumbrical.



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Thenar space
Thenar refers to the thumb, and this space is situated between the first digit and thumb. One of the deep flexors (extrinsic muscle) is located in here.

Interossei muscle (intrinsic)
This interossei muscle sits between metacarpal bones and will unite with tendons to allow extension using extrinsic muscles.

Arteries, veins and nerves
These supply fresh oxygenated blood (and take away deoxygenated blood) to hand muscles.

Ulnar nerve
This nerve stretches down the forearm into the hand and allows for sensory information to be passed from hand to brain.

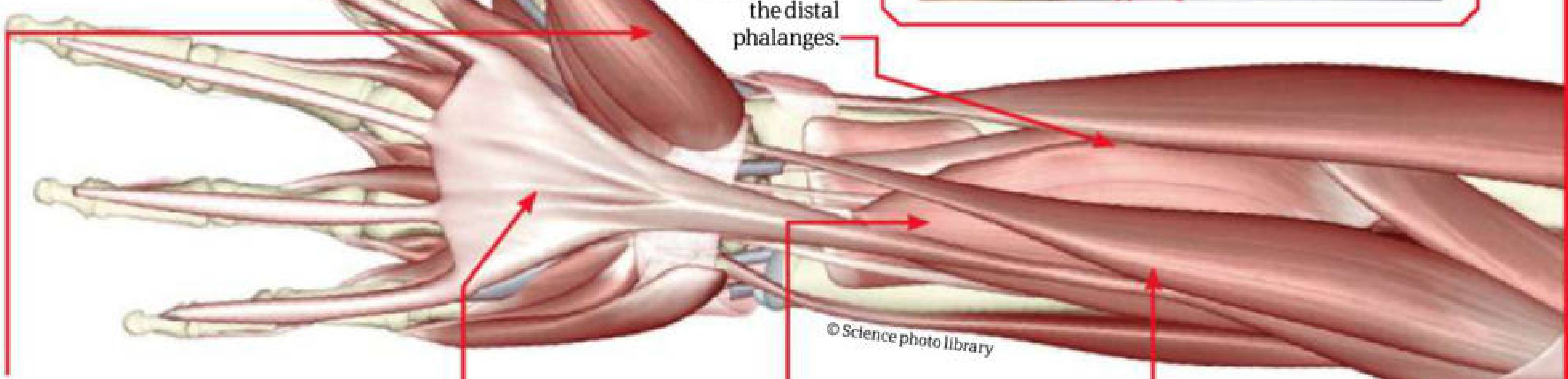
Hypothenar muscle (intrinsic)
Hypothenar refers to the little finger and this muscle group is one of the intrinsic muscles.

Insertion of flexor tendon
This is where the tendon attaches the flexor muscle to the finger bones to allow articulation.

Mid palmar space
Tendons and intrinsic muscles primarily inhabit this space within the hand.

Forearm muscles

Extrinsic muscles are so called because they are primarily situated outside the hand, the body of the muscles situated along the underside or front of the forearm. This body of muscles actually breaks down into two quite distinct groups: the flexors and the extensors. The flexors run alongside the underside of the arm and allow for the bending of the digits, whereas the extensor muscles' main purpose is the reverse of this action, to straighten the digits. There are both deep and superficial flexors and extensors, and which are used at any one time depends on the digit to be moved.



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Deep flexors
Digits have two extrinsic flexors that allow them to bend: the deep flexor and the superficial. The deep flexor attaches to the distal phalanges.

Tendons and intrinsics
These attach the flexor muscles to the phalanges, and facilitate bending. Tendons also interact with the intrinsics and extensors in the wrist, palm and forearm to straighten the digits.

Thenars
The intrinsic group of muscles is used to flex the thumb and control its sideways movement.

Superficial flexors
The other flexor that acts on the digits is the superior flexor, which attaches to the intermediate phalanges.

Extensors
Extensors on the back of the forearm straighten the digits. Divided into six sections, their connection to the digits is complex.

Opposable thumbs

Increased articulation of the thumb has been heralded as a key factor in human evolution. It allowed for increased grip and control, and for tool use to develop among human ancestors as well as other primates. This then facilitated major cultural advances, such as writing. Alongside the four other flexible digits, the opposable thumb makes the human hand one of the most dexterous in the world. A thumb can only be classified as opposable when it can be brought opposite to the other digits.

Left-handed or right-handed?

The most common theory for why some individuals are left handed is that of the 'disappearing twin'. This supposes that the left-handed individual was actually one of a set of twins, but that in the early stages of development the other, right handed, twin died. However, it's been found that dominance of one hand is directly linked with hemisphere dominance in the brain, as in many other paired organs.

Individuals who somehow damage their dominant hand for extended periods of time can actually change to use the other hand, proving the impact and importance of environment and extent to which humans can adapt.

Opposable thumbs have enabled humans and primates to use tools

How do your feet work?

Feet are immensely complex structures, yet we put huge amounts of pressure on them every day. How do they cope?

The human foot and ankle is crucial for locomotion and is one of the most complex structures of the human body. This intricate structure is made up of no less than 26 bones, 20 muscles, 33 joints – although only 20 are articulated – as well as numerous tendons and ligaments. Tendons connect the muscles to the bones and facilitate movement of the foot, while ligaments hold the tendons in place and help the foot move up and down to initiate walking. Arches in the foot are formed by ligaments, muscles and foot bones and help to distribute weight, as well as making it easier for the foot to operate efficiently when walking and running. It is due to the unique structure of the foot and the way it distributes pressure throughout all aspects that it can withstand constant pressure throughout the day.

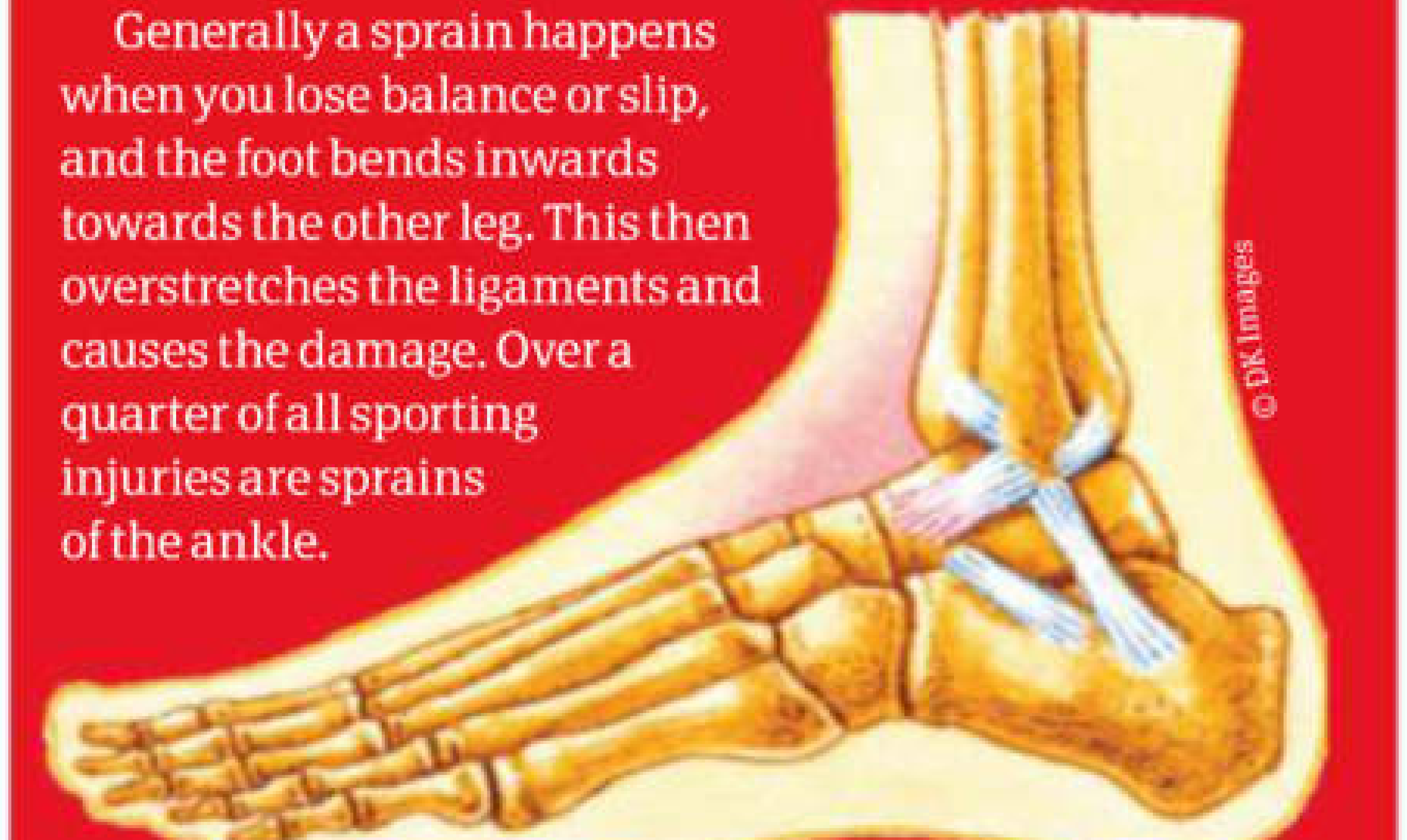
One of the other crucial functions of the foot is to aid balance, and the toes are a crucial aspect of this. The big toe in particular helps in this area, as we can grip the ground with it if we feel that we are losing balance.

The skin, nerves and blood vessels make up the rest of the foot, helping to hold the shape and also supplying it with all the necessary minerals, oxygen and energy to help keep it moving easily and constantly.

What happens when you sprain your ankle?

A sprained ankle is the most common type of soft tissue injury. The severity of the sprain can depend on how you sprained the ankle, and a minor sprain will generally consist of simply a stretched or only partially torn ligament. However, more severe sprains can cause the ligament to tear completely, could or even force a piece of bone to break off.

Generally a sprain happens when you lose balance or slip, and the foot bends inwards towards the other leg. This then overstretches the ligaments and causes the damage. Over a quarter of all sporting injuries are sprains of the ankle.



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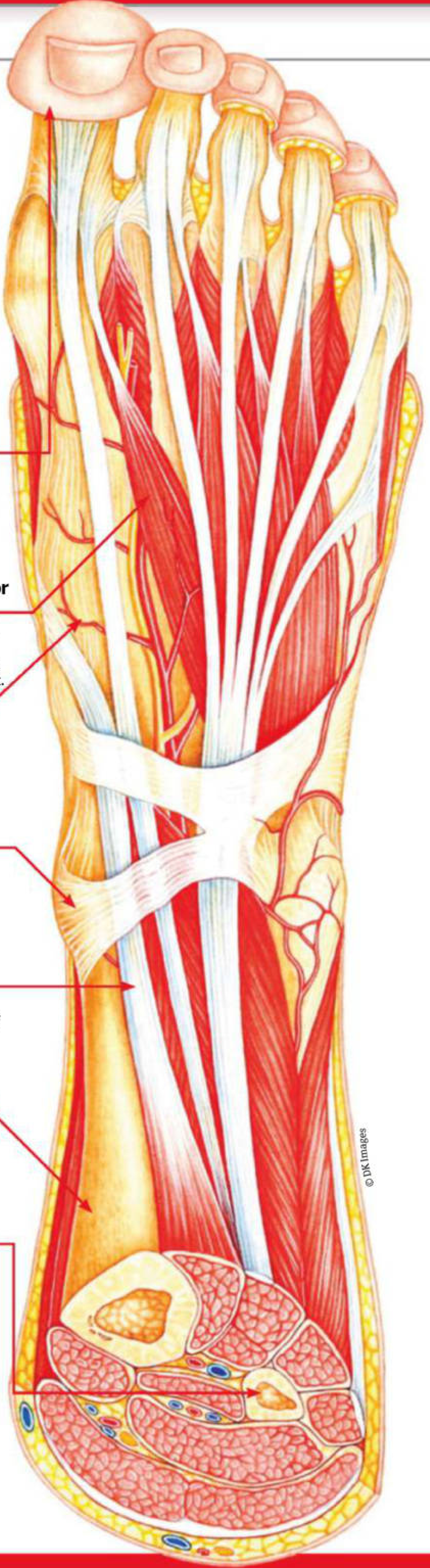

Toes

Terminal aspects of the foot that aid balance by grasping onto the ground. They are the equivalent of fingers in the foot structure.

Muscles – including the extensor digitorum brevis muscle

Muscles within the foot help the foot lift and articulate as necessary. The extensor digitorum brevis muscle sits on the top of the foot, and helps flex digits two-four on the foot.

Blood vessels

These supply blood to the foot, facilitating muscle operation by supplying energy and oxygen and removing deoxygenated blood.

Ligaments

Ligaments support the tendons and help to form the arches of the foot, spreading weight across it.

Tendons (extensor digitorum longus, among others)

Fibrous bands of tissue which connect muscles to bones. They can withstand a lot of tension and link various aspects of the foot, facilitating movement.

Tibia

The larger and stronger of the lower leg bones, this links the knee and the ankle bones of the foot.

Fibula

This bone sits alongside the tibia, also linking the knee and the ankle.

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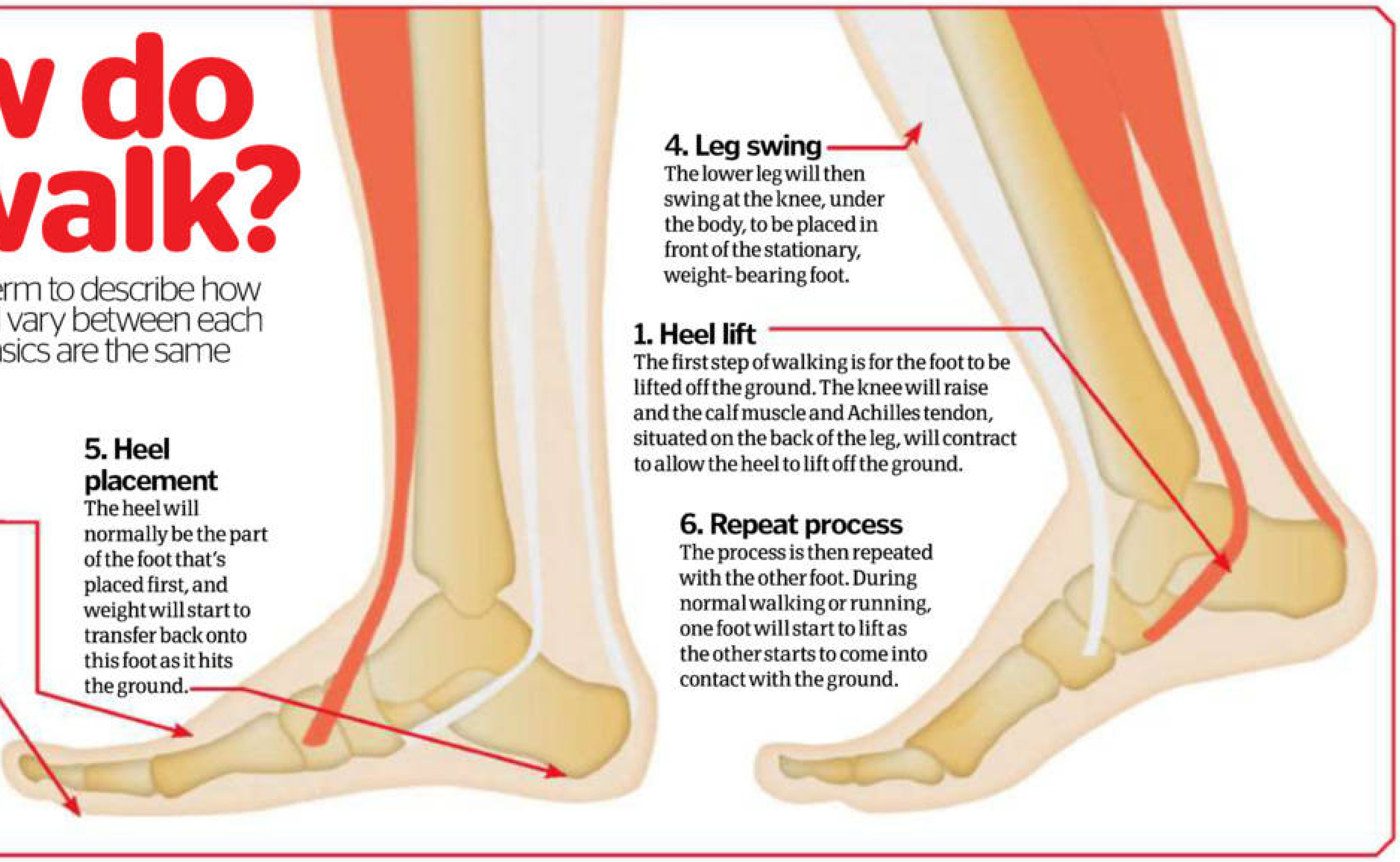
> "The structure of the foot and how the elements work together"

How do we walk?

'Human gait' is the term to describe how we walk. This gait will vary between each person, but the basics are the same



2. Weight transfer
The weight will transfer fully to the foot still in contact with the ground, normally with a slight leaning movement of the body.

3. Foot lift
After weight has transferred and the individual feels balanced, the ball of the first foot will then lift off the ground, raising the thigh.

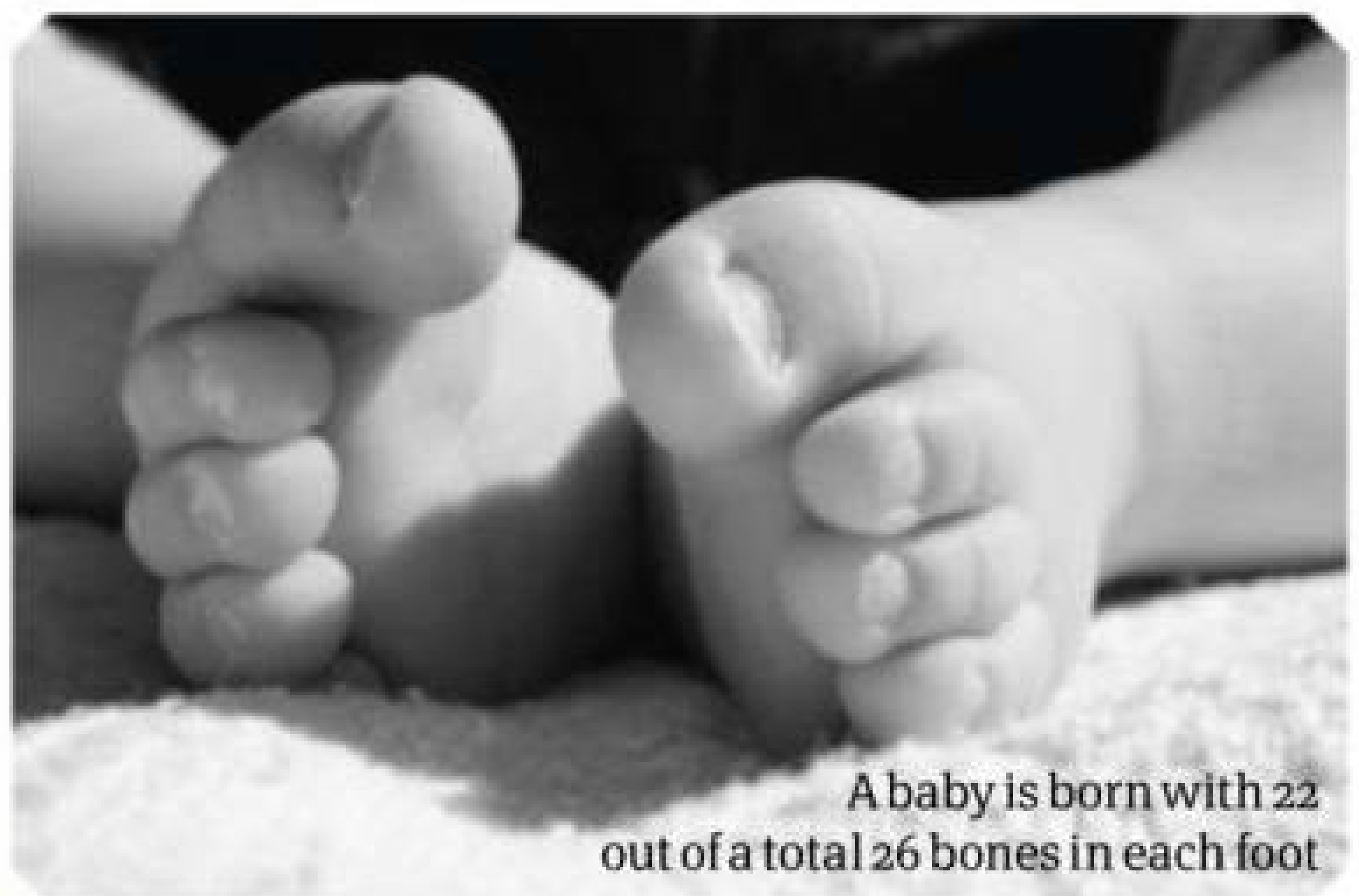
5. Heel placement
The heel will normally be the part of the foot that's placed first, and weight will start to transfer back onto this foot as it hits the ground.

4. Leg swing
The lower leg will then swing at the knee, under the body, to be placed in front of the stationary, weight-bearing foot.

1. Heel lift
The first step of walking is for the foot to be lifted off the ground. The knee will raise and the calf muscle and Achilles tendon, situated on the back of the leg, will contract to allow the heel to lift off the ground.

6. Repeat process
The process is then repeated with the other foot. During normal walking or running, one foot will start to lift as the other starts to come into contact with the ground.

Bones of the foot



A baby is born with 22 out of a total 26 bones in each foot

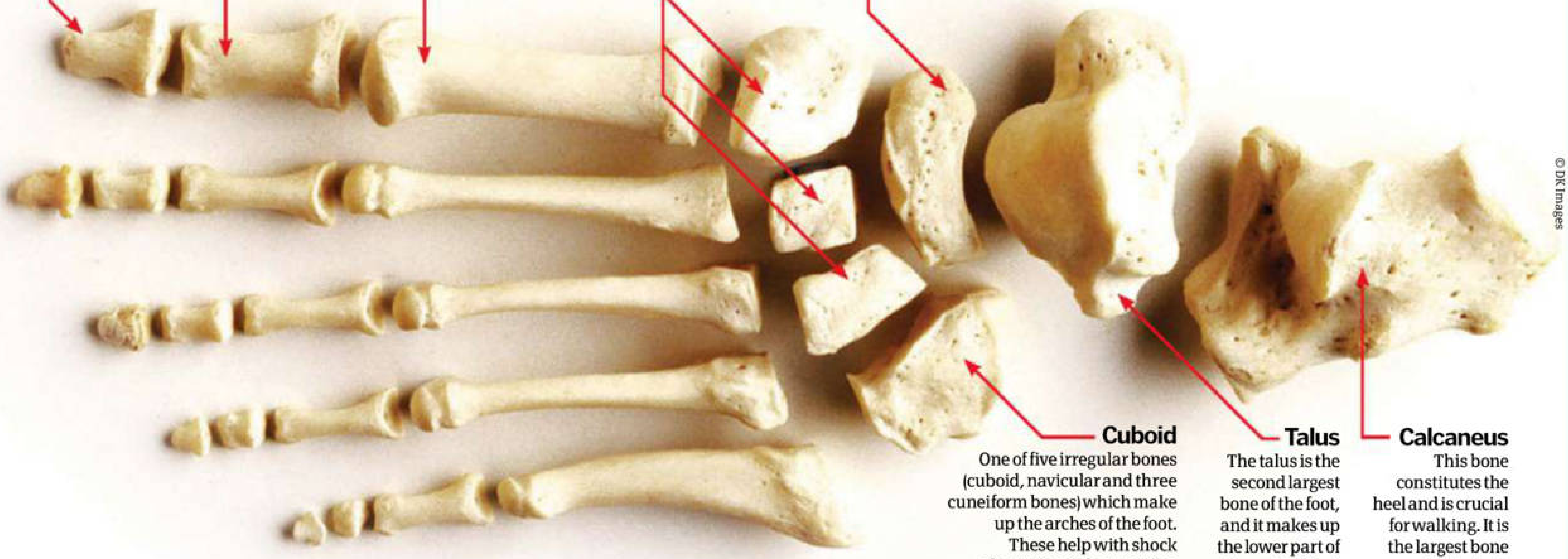
Distal phalanges
The bones which sit at the far end of the foot and make up the tips of the toes.

Proximal phalanges
These bones link the metatarsals and the distal phalanges and stretch from the base of the toes.

Metatarsals
The five, long bones that are the metatarsals are located between the tarsal bones and the phalanges. These are the equivalent of the metacarpals in the hand.

Cuneiforms bones (three)
Three bones that fuse together during bone development and sit between the metatarsals and the talus.

Navicular
This bone, which is so named due to its resemblance to a boat, articulates with the three cuneiform bones.



Cuboid
One of five irregular bones (cuboid, navicular and three cuneiform bones) which make up the arches of the foot. These help with shock absorption in locomotion.

Talus
The talus is the second largest bone of the foot, and it makes up the lower part of the ankle joint.

Calcaneus
This bone constitutes the heel and is crucial for walking. It is the largest bone in the foot.

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The human skeleton explained

Without a skeleton, we would not be able to live. It is what gives us our shape and structure and its presence allows us to operate on a daily basis. It's also a fascinating evolutionary link to all other living and extinct vertebrates

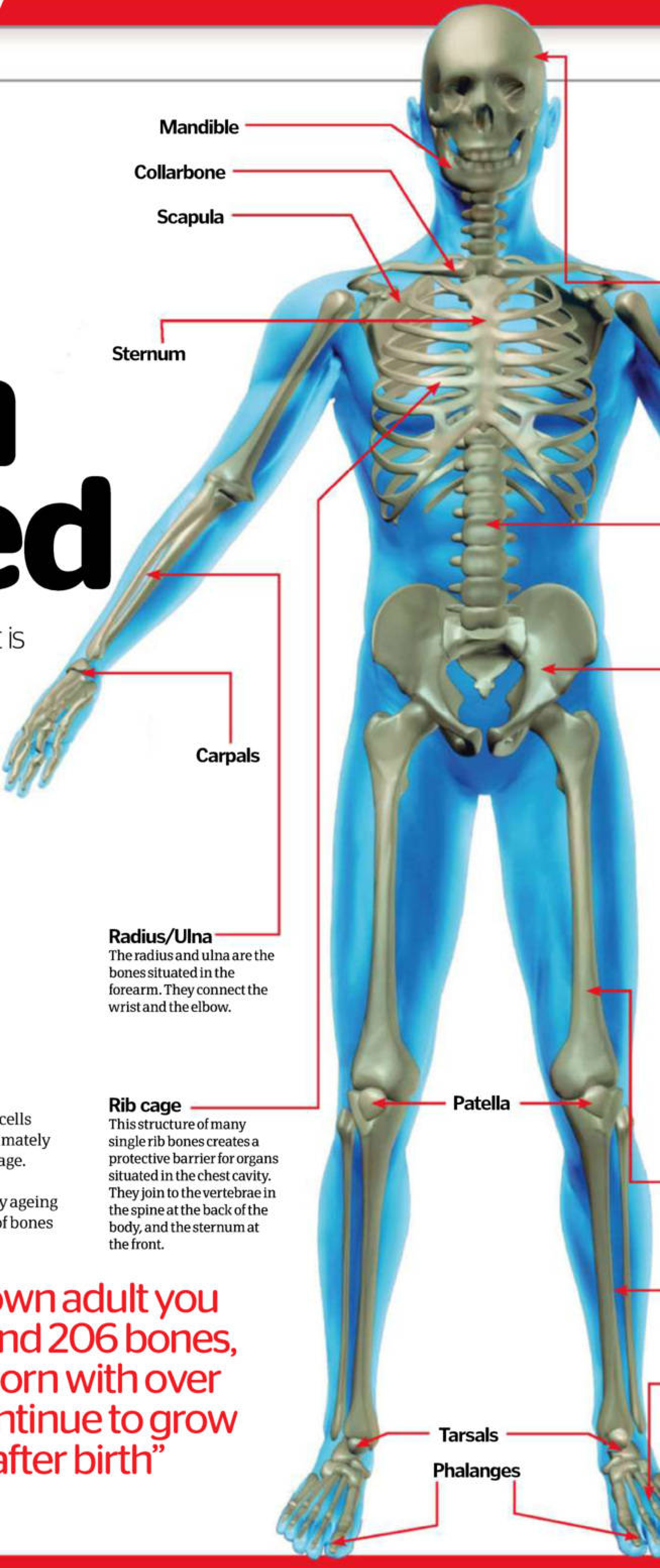
The human skeleton is crucial for us to live. It keeps our shape and muscle attached to the skeleton allows us the ability to move around, while also protecting crucial organs that we need to survive. Bones also produce blood cells within bone marrow and store minerals we need released on a daily basis.

As a fully grown adult you will have around 206 bones, but you are born with over 270, which continue to grow, strengthen and fuse after birth until around 18 in females and 20 in males. Human skeletons actually do vary between sexes in structure also. One of the most obvious areas is the pelvis as a female must be able to give birth, and therefore hips are comparatively shallower and wider. The cranium also becomes more robust in males due to heavy muscle attachment and a male's chin is often more prominent. Female skeletons are generally more delicate overall. However, although there are several methods, sexing can be difficult because of the level of variation we see within the species.

Bones are made up of various different elements. In utero, the skeleton takes shape as cartilage, which then starts to calcify and develop during gestation and following birth. The primary element that makes up bone, osseous tissue, is actually mineralised calcium phosphate, but other forms of tissue such as marrow, cartilage and blood vessels are also contained in the overall structure. Many individuals think that bones are solid, but actually inner bone is porous and full of little holes.

As we age, so do our bones. Even though cells are constantly being replaced, and therefore no cell in our body is more than 20 years old, they are not replaced with perfect, brand-new cells. The cells contain errors in their DNA and ultimately our bones therefore weaken as we age. Conditions such as arthritis and osteoporosis can often be caused by ageing and cause issues with weakening of bones and reduced movement ability.

> "As a fully grown adult you will have around 206 bones, but you are born with over 270, which continue to grow and fuse after birth"

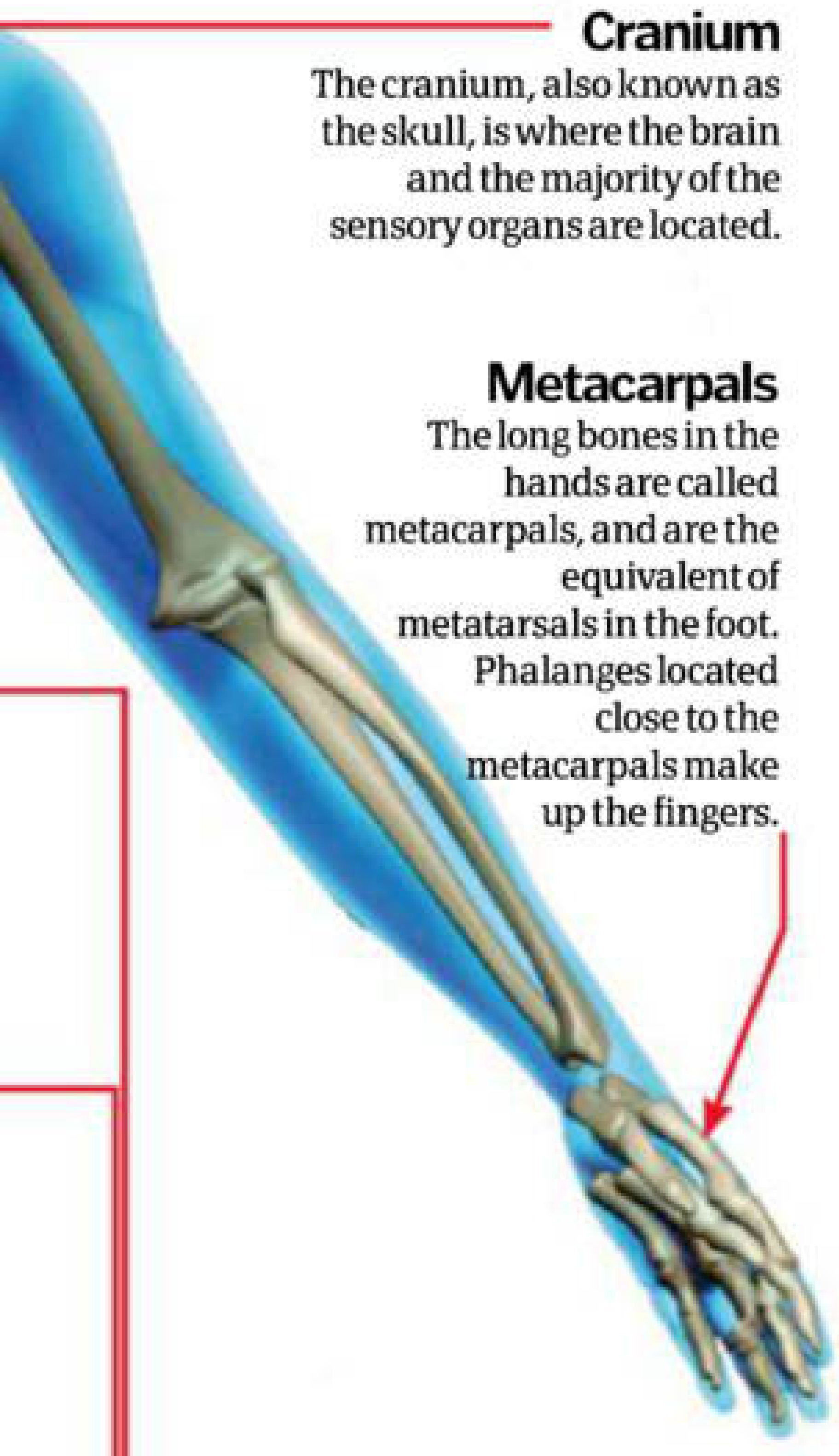


Radius/Ulna
The radius and ulna are the bones situated in the forearm. They connect the wrist and the elbow.

Rib cage
This structure of many single rib bones creates a protective barrier for organs situated in the chest cavity. They join to the vertebrae in the spine at the back of the body, and the sternum at the front.

Inside our skeleton

How the human skeleton works and keeps us upright



Cranium
The cranium, also known as the skull, is where the brain and the majority of the sensory organs are located.

Metacarpals
The long bones in the hands are called metacarpals, and are the equivalent of metatarsals in the foot. Phalanges located close to the metacarpals make up the fingers.

Vertebrae
There are three main kinds of vertebrae (excluding the sacrum and coccyx) – cervical, thoracic and lumbar. These vary in strength and structure because they carry different pressure within the spine.

Pelvis
This is the transitional joint between the trunk of the body and the legs. It is one of the key areas in which we can see the skeletal differences between the sexes.

Femur
This is the largest and longest single bone in the body. It connects to the pelvis using a ball and socket joint.

Fibula/Tibia
These two bones form the lower leg bone and connect to the knee joint and the foot.

Metatarsals
These are the five long bones in the foot that aid balance and movement. Phalanges located close to the metatarsals are the bones which are present in toes.

Breaking bones

Whether it's a complete break or just a fracture, both can take time to heal properly

A typical cast for when someone has managed to break a bone. Unbelievably, a saw is the method of choice for removal!

If you simply fracture the bone, you may just need to keep it straight and keep pressure off it until it heals. However, if you break it into more than one piece, you may need metal pins inserted into the bone to realign it or plates to cover the break in order for it to heal properly. The bone heals by producing new cells and tiny blood vessels where the fracture or break has occurred and these then rejoin up. For most breaks or fractures, a cast external to the body will be put on around the bone to take pressure off the bone to ensure that no more damage is done and the break can heal.

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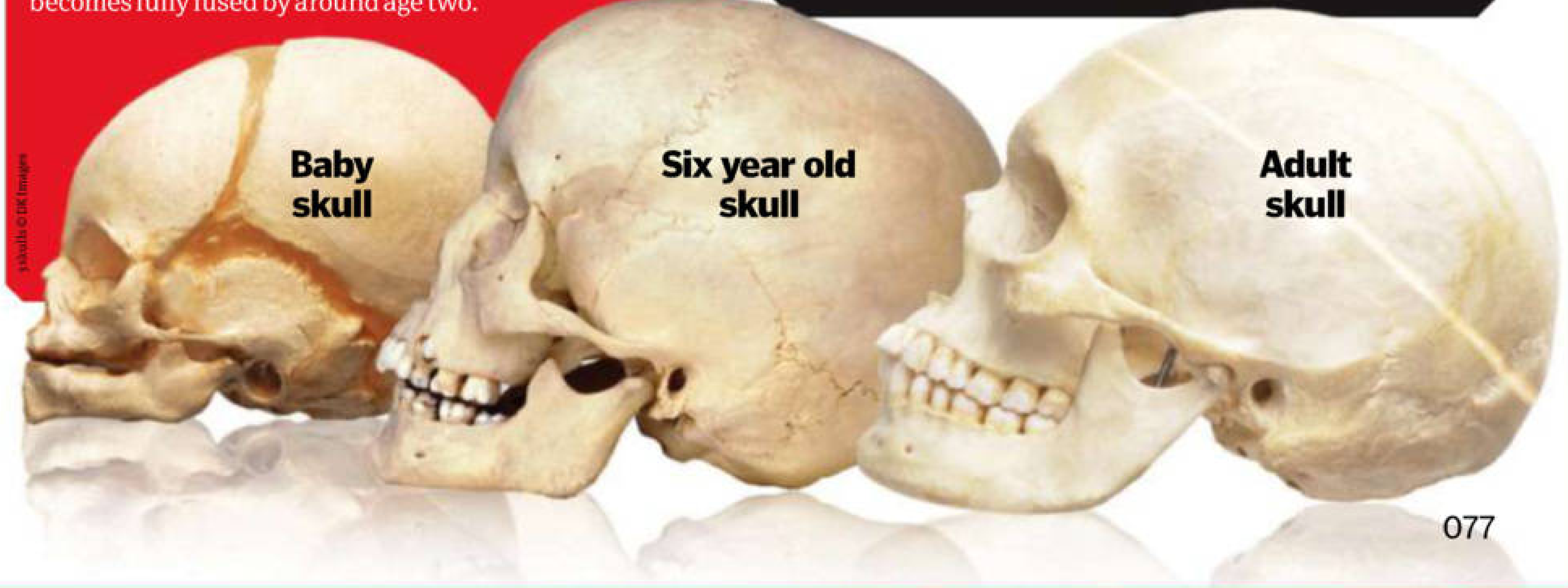
Skull development

When we are born, many of our bones are still soft and are not yet fused – this process occurs later during our childhood

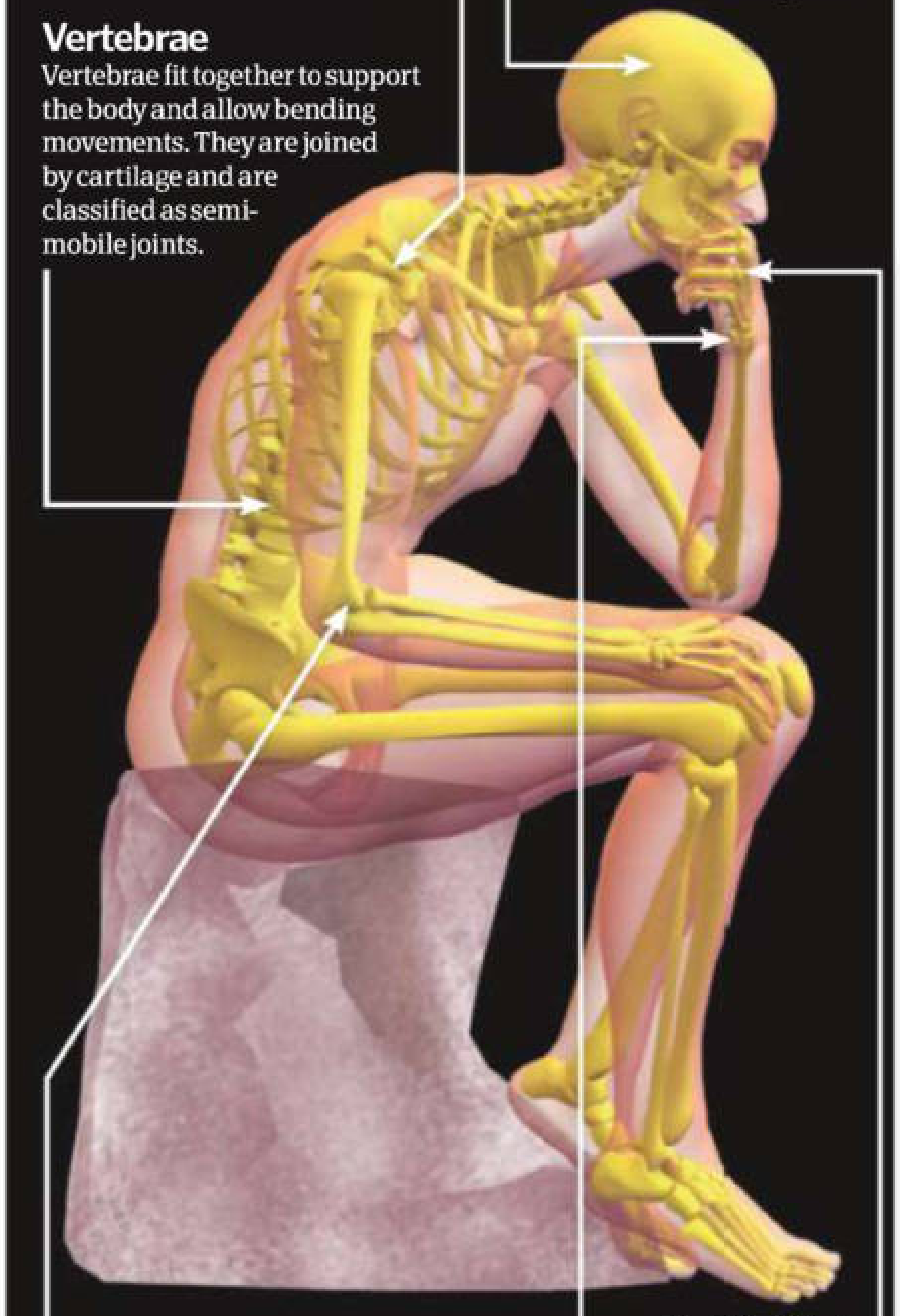
The primary reasons for the cranium in particular not to be fully fused at birth is to allow the skull to flex as the baby is born and also to allow the extreme rate of growth that occurs in the first few years of childhood following birth. The skull is actually in seven separate plates when we are born and over the first two years these pieces fuse together slowly and ossify. The plates start suturing together early on, but the anterior fontanel – commonly known as the soft spot – will take around 18 months to fully heal. Some other bones, such as the five bones located in the sacrum, don't fully fuse until late teens or early twenties, but the cranium becomes fully fused by around age two.



3 skulls © DK Images

How our joints work

The types of joints in our body explained



Ball and socket joints
Both the hip and the shoulder joints are ball and socket joints. The femur and humerus have ball shaped endings, which turn in a cavity to allow movement.

Skull sutures
Although not generally thought of as a 'joint', all the cranial sutures present from where bones have fused in childhood are in fact immoveable joints.

Vertebrae
Vertebrae fit together to support the body and allow bending movements. They are joined by cartilage and are classified as semi-mobile joints.

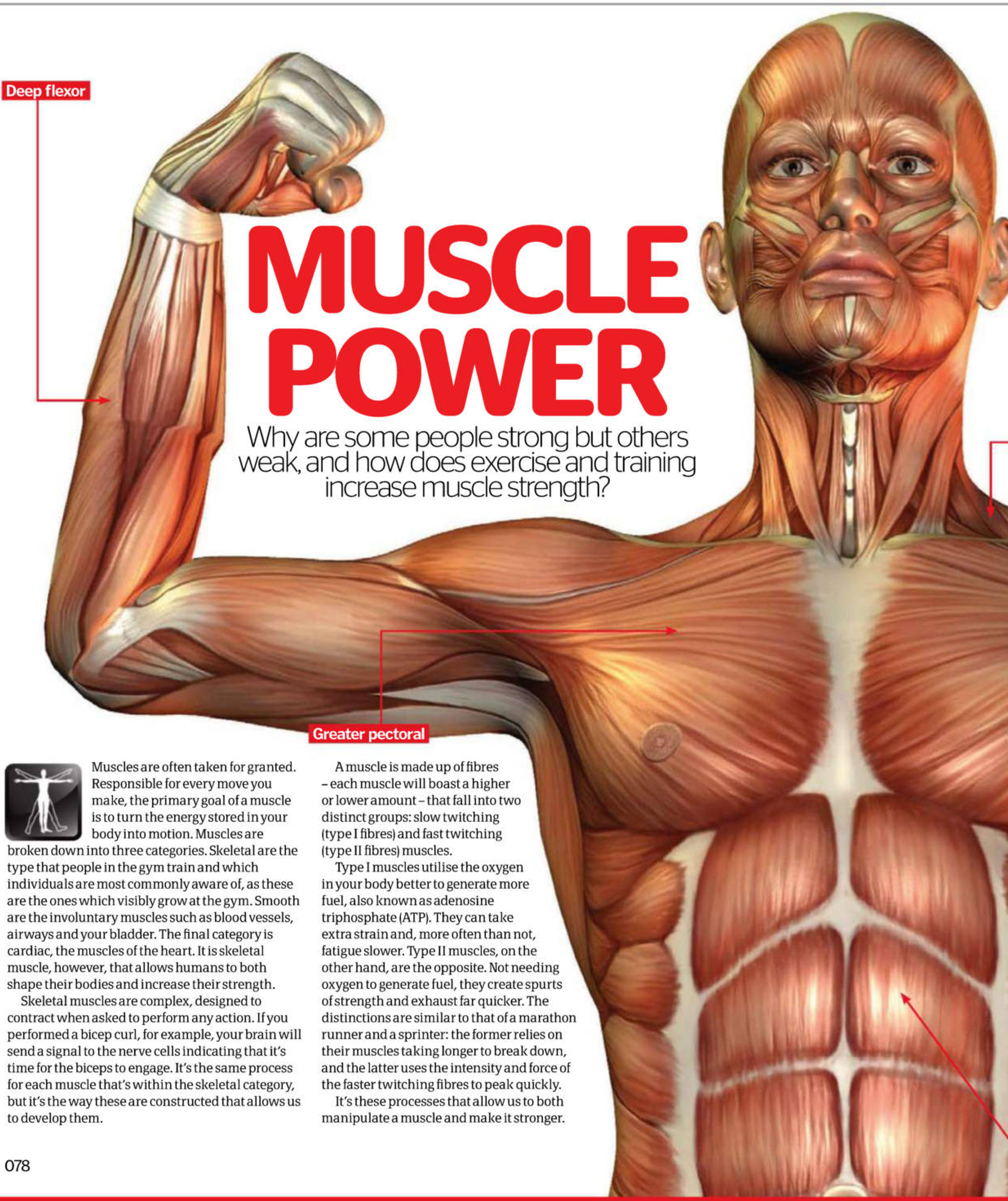
Hinged joints
Both elbows and knees are hinged joints. These joints only allow limited movement in one direction. The bones fit together and are moved by muscles.

Gliding joints
Some movement can be allowed when flat bones 'glide' across each other. The wrist bones – the carpals – operate like this, moved by ligaments.

Saddle joints
The only place we see this joint in humans is the thumb. Movement is limited in rotation, but the thumb can move back, forward and to the sides.

MUSCLE POWER

Why are some people strong but others weak, and how does exercise and training increase muscle strength?



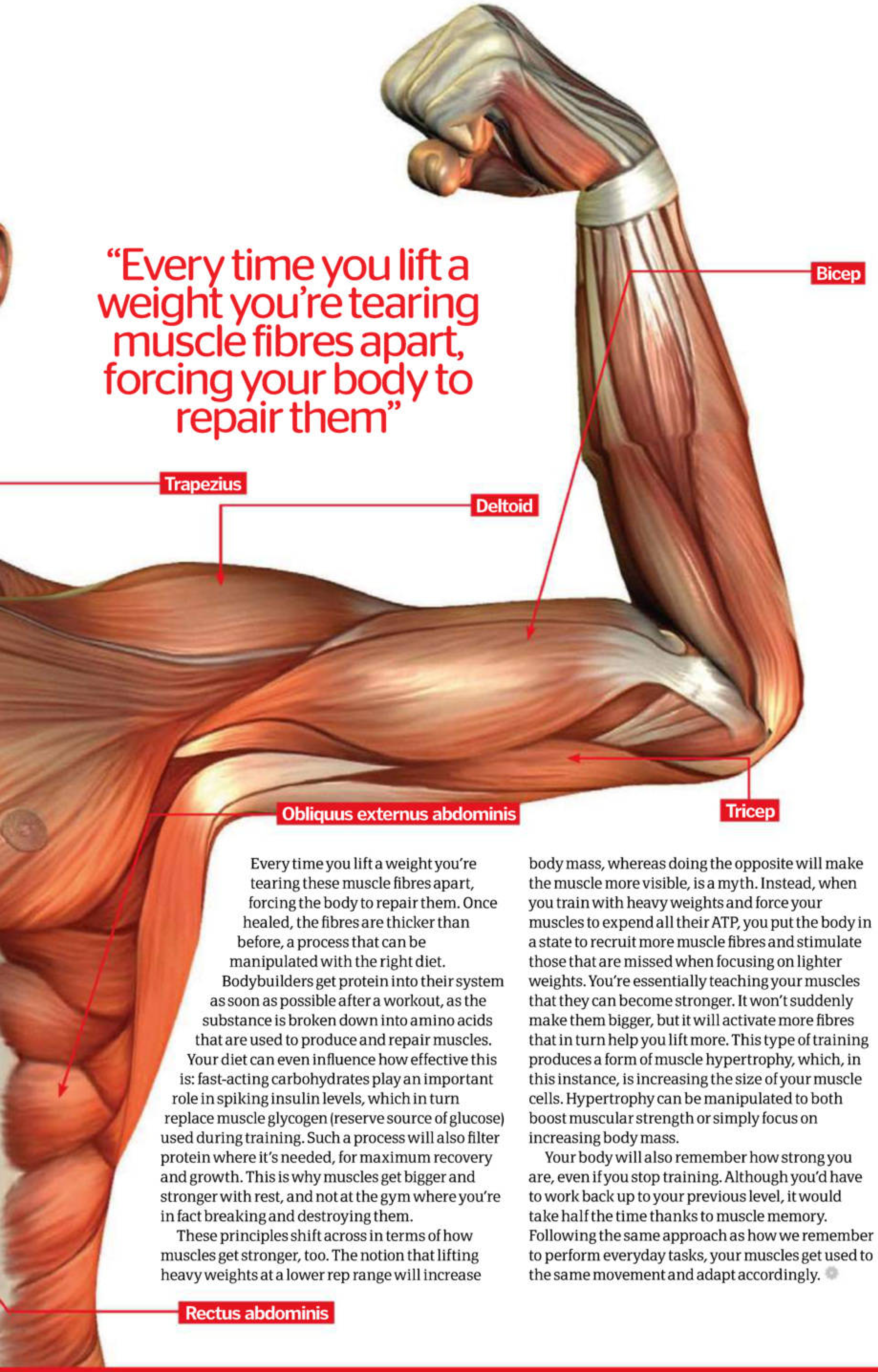
Muscles are often taken for granted. Responsible for every move you make, the primary goal of a muscle is to turn the energy stored in your body into motion. Muscles are broken down into three categories. Skeletal are the type that people in the gym train and which individuals are most commonly aware of, as these are the ones which visibly grow at the gym. Smooth are the involuntary muscles such as blood vessels, airways and your bladder. The final category is cardiac, the muscles of the heart. It is skeletal muscle, however, that allows humans to both shape their bodies and increase their strength.

Skeletal muscles are complex, designed to contract when asked to perform any action. If you performed a bicep curl, for example, your brain will send a signal to the nerve cells indicating that it's time for the biceps to engage. It's the same process for each muscle that's within the skeletal category, but it's the way these are constructed that allows us to develop them.

A muscle is made up of fibres – each muscle will boast a higher or lower amount – that fall into two distinct groups: slow twitching (type I fibres) and fast twitching (type II fibres) muscles.

Type I muscles utilise the oxygen in your body better to generate more fuel, also known as adenosine triphosphate (ATP). They can take extra strain and, more often than not, fatigue slower. Type II muscles, on the other hand, are the opposite. Not needing oxygen to generate fuel, they create spurts of strength and exhaust far quicker. The distinctions are similar to that of a marathon runner and a sprinter: the former relies on their muscles taking longer to break down, and the latter uses the intensity and force of the faster twitching fibres to peak quickly.

It's these processes that allow us to both manipulate a muscle and make it stronger.



> "Every time you lift a weight you're tearing muscle fibres apart, forcing your body to repair them"

Every time you lift a weight you're tearing these muscle fibres apart, forcing the body to repair them. Once healed, the fibres are thicker than before, a process that can be manipulated with the right diet.

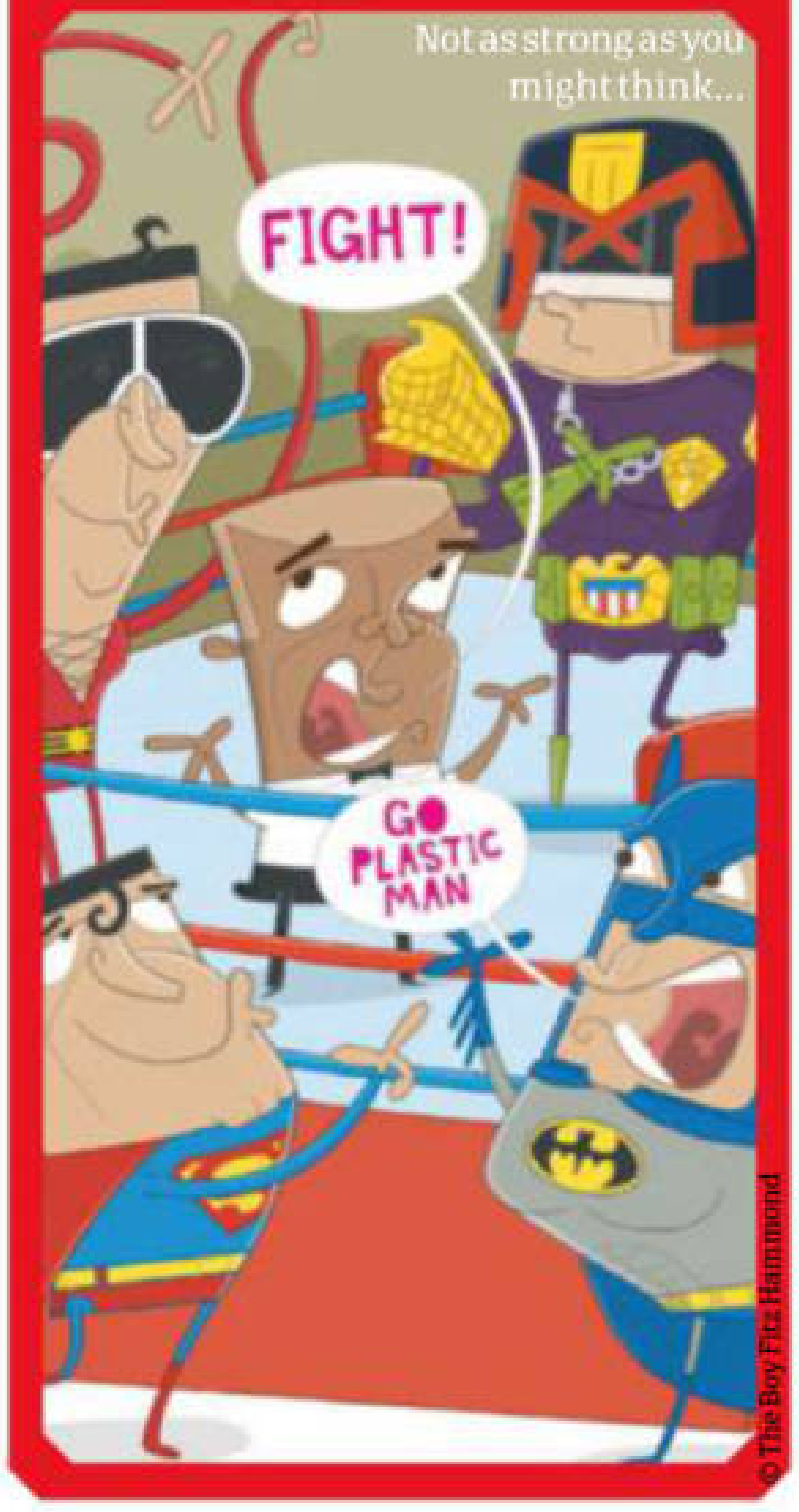
Bodybuilders get protein into their system as soon as possible after a workout, as the substance is broken down into amino acids that are used to produce and repair muscles. Your diet can even influence how effective this is: fast-acting carbohydrates play an important role in spiking insulin levels, which in turn replace muscle glycogen (reserve source of glucose) used during training. Such a process will also filter protein where it's needed, for maximum recovery and growth. This is why muscles get bigger and stronger with rest, and not at the gym where you're in fact breaking and destroying them.

These principles shift across in terms of how muscles get stronger, too. The notion that lifting heavy weights at a lower rep range will increase body mass, whereas doing the opposite will make the muscle more visible, is a myth. Instead, when you train with heavy weights and force your muscles to expend all their ATP, you put the body in a state to recruit more muscle fibres and stimulate those that are missed when focusing on lighter weights. You're essentially teaching your muscles that they can become stronger. It won't suddenly make them bigger, but it will activate more fibres that in turn help you lift more. This type of training produces a form of muscle hypertrophy, which, in this instance, is increasing the size of your muscle cells. Hypertrophy can be manipulated to both boost muscular strength or simply focus on increasing body mass.

Your body will also remember how strong you are, even if you stop training. Although you'd have to work back up to your previous level, it would take half the time thanks to muscle memory. Following the same approach as how we remember to perform everyday tasks, your muscles get used to the same movement and adapt accordingly.

The bigger they are...

Just because you look like The Hulk doesn't mean you're going to have the comic book character's strength. If you lift heavy weights for a low number of repetitions, you're training the muscle to take a more intense load due to the formation of new fibres. That doesn't mean you'll have the size to back it up, however, as mass corresponds to the number of calories consumed. The more food that's eaten, the quicker and more efficiently the muscle will be repaired. This is why plenty of power lifters who can pick up an incredible amount don't look like bodybuilders. Not only do they concentrate on pure strength, they also consume a massive number of calories. A bodybuilder, meanwhile, will sculpt his diet to shape and increase muscle size.



Not as strong as you might think...

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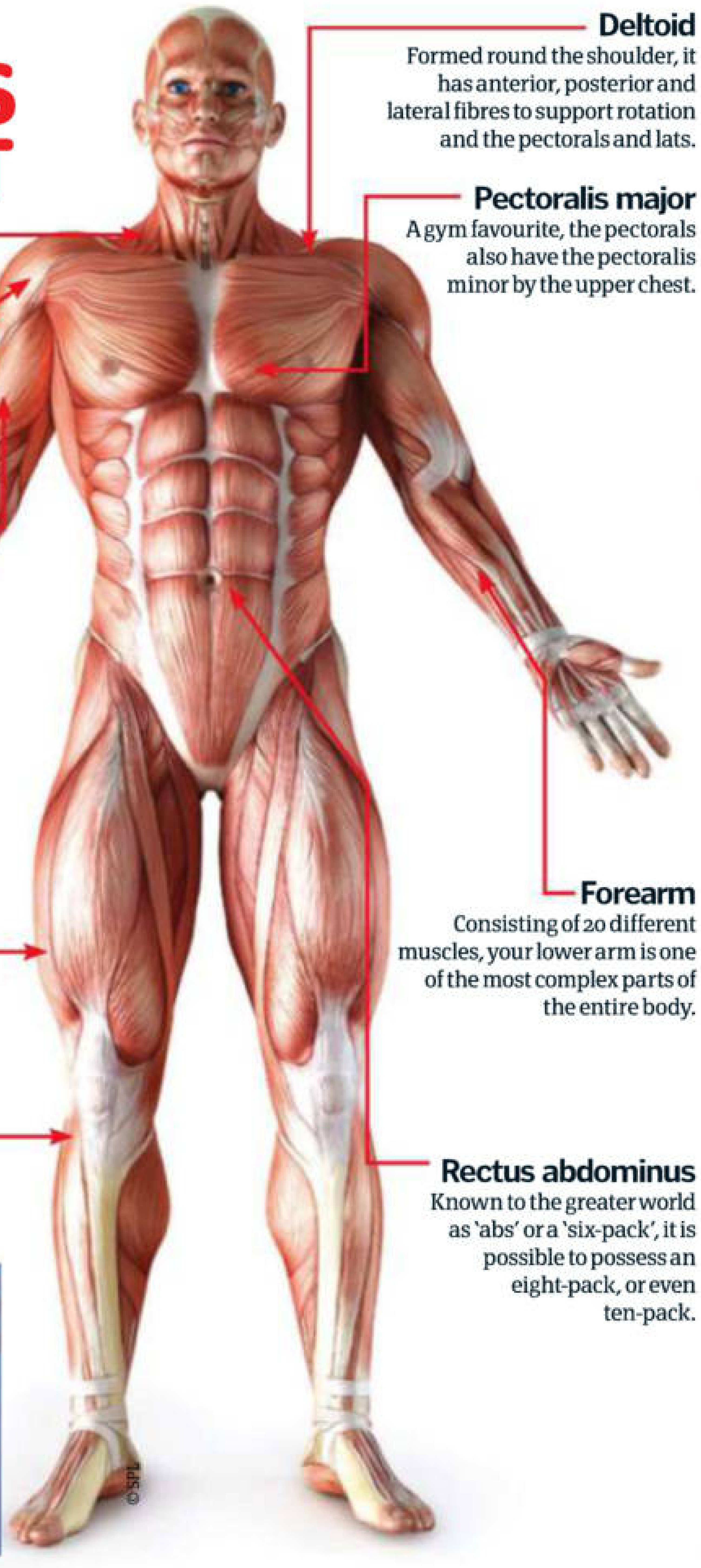
MUSCLES IN FRONT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Trapezius
A superficial muscle that moves the scapulae (in the rotator cuff) and supports the arm.

Biceps brachii
Consists of a long and short head to, among other things, allow rotation of the forearm and elbow.

Vastus lateralis
The largest part of your quadriceps muscle, the quad also has the rectus femoris, vastus medialis and vastus intermedius.

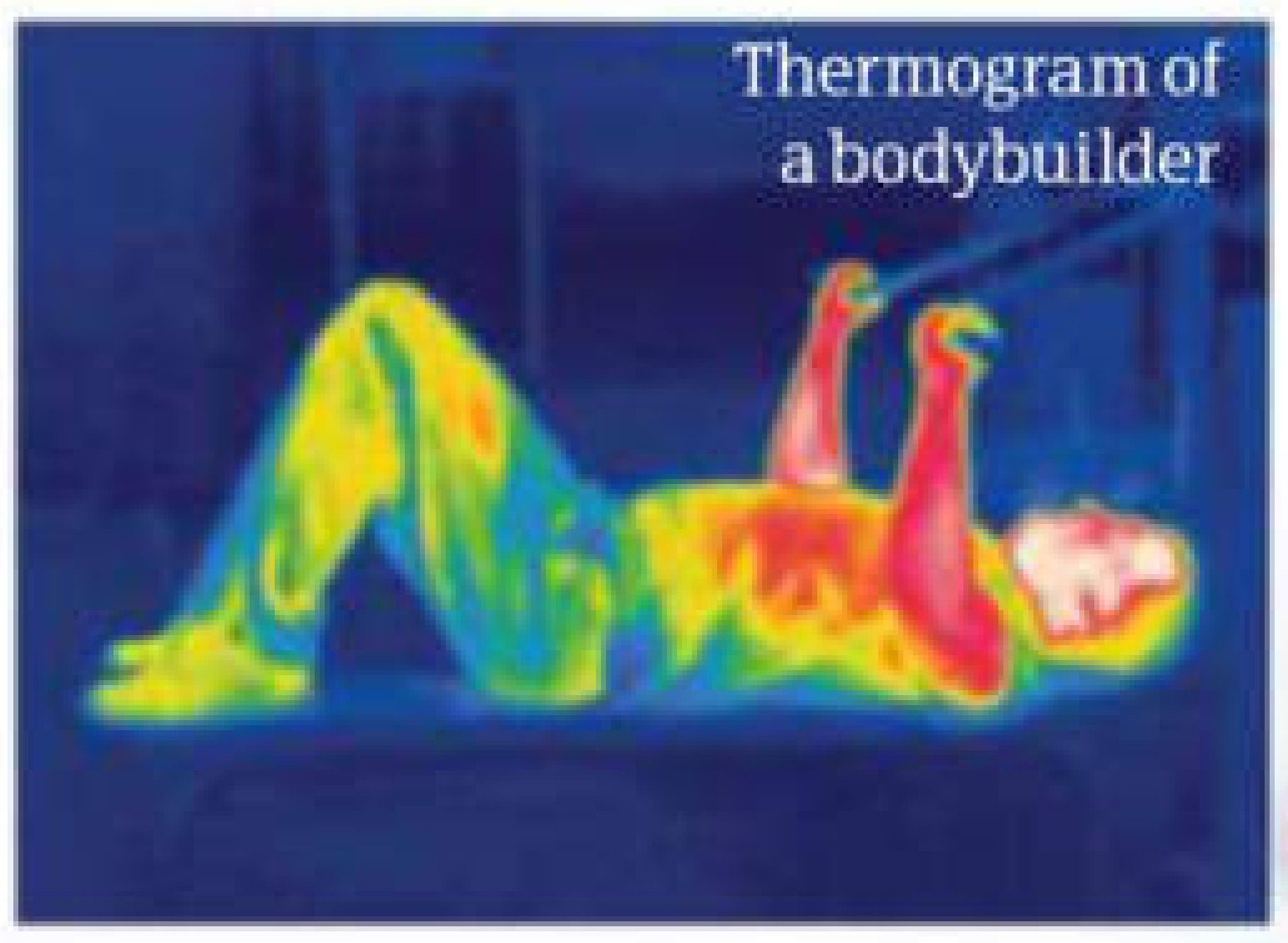
Gastrocnemius
Meaning 'stomach of leg', the calve is incredibly hard to develop due to the pressure it is put under on a daily basis.

Deltoid
Formed round the shoulder, it has anterior, posterior and lateral fibres to support rotation and the pectorals and lats.

Pectoralis major
A gym favourite, the pectorals also have the pectoralis minor by the upper chest.

Forearm
Consisting of 20 different muscles, your lower arm is one of the most complex parts of the entire body.

Rectus abdominus
Known to the greater world as 'abs' or a 'six-pack', it is possible to possess an eight-pack, or even ten-pack.


Thermogram of a bodybuilder

Shoulders

Exercise name: Military press

How to do it: Using weights, bend your legs, lift up the bar in line with your shoulders and push from your deltoids until your arms are straight. Repeat.

Details: With the correct weight and intensity, it'll tear many muscles apart and increase your strength.

STRENGTH RATING: ●●●●○

Mid-section

Exercise name: Side plank

How to do it: Lay on your side and hoist your body up using the leg and arm you're resting on. Hold this position for as long as you can.

Details: The side plank will trigger both abdominals and mid-section, for a more efficient centre of gravity.

STRENGTH RATING: ●●○○○

Calves

Exercise name: Calve raise

How to do it: Using a Smith machine, stand under the barbell and place it on your trapezius muscles. Push from calves and stand on your tiptoes.

Details: Extremely difficult to enhance, the calve raise when done with a barbell will target this muscle.

STRENGTH RATING: ●●○○○

Chest

Exercise name: Bench press

How to do it: Lie on a bench and grab a barbell, hands about shoulder width. Bring the bar to chest level and lower until arms are at 90°. Push upwards.

Details: The bench press isn't merely beneficial for your chest; it also works your shoulders and triceps.

STRENGTH RATING: ●●●●○

Biceps

Exercise name: Bicep curl

How to do it: Raise a dumbbell from your side up to your shoulder rotating the arm so the palm with the weight faces up. Then lower and repeat.

Details: The biceps' relatively small size compared to other muscle groups means they're quite easy to target.

STRENGTH RATING: ●●○○○

Forearms

Exercise name: Hammer curls

How to do it: Hold a dumbbell in each hand with palms facing your body. Curl the weight up to your chest, keeping elbows locked. Lower down.

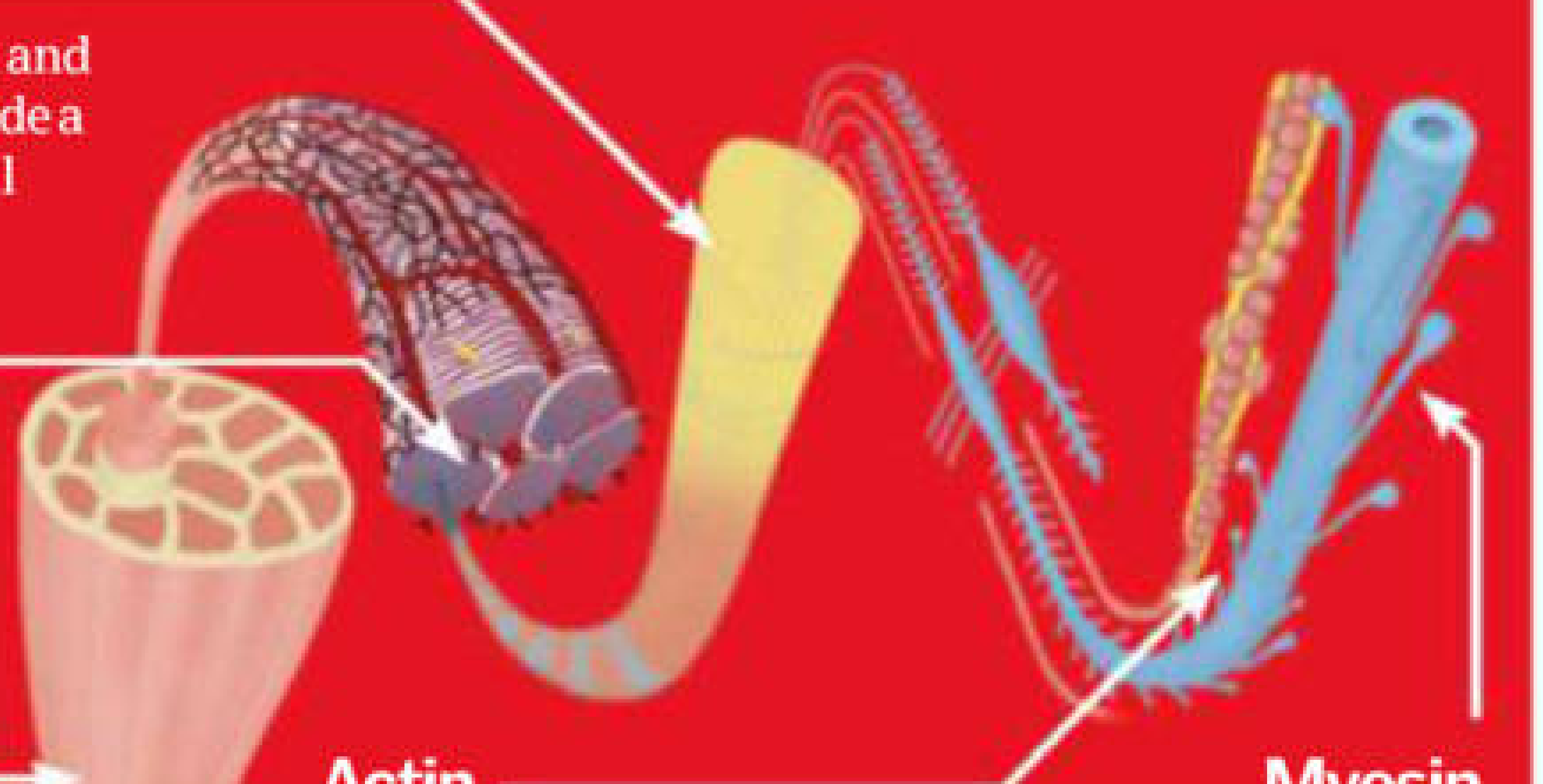
Details: Performed with a heavy weight, you can improve your grip and increase arm strength.

STRENGTH RATING: ●●●○○

Inside your muscle

A muscle contracts when a fibre is kicked into gear as tension is put upon it. Myofibrils, which are found within a fibre, are made up of actin and myosin. When these two threads join the myofibril shortens, or contracts. If you straighten your arm, keeping your palm facing up, and measure the length of your bicep muscle, you'll find it will become a lot smaller if you curl your hand towards the shoulder.

There are multiple types of contractions, though. Isometric contractions occur when the angle of the joint or length of muscle do not change, for example holding a dumbbell at arm's length and fighting the resistance. Such exercises are usually adapted to try and increase strength. Isotonic contractions are the opposite and more common, such as traditional weightlifting where, as mentioned, the muscle shortens with contraction. Although this can also be used for strength training, it's beneficial for expanding muscle size.



Myofibril
Housing the two filaments actin and myosin, this is what's found inside a muscle fibre. When the myofibril shortens, a muscle contracts.

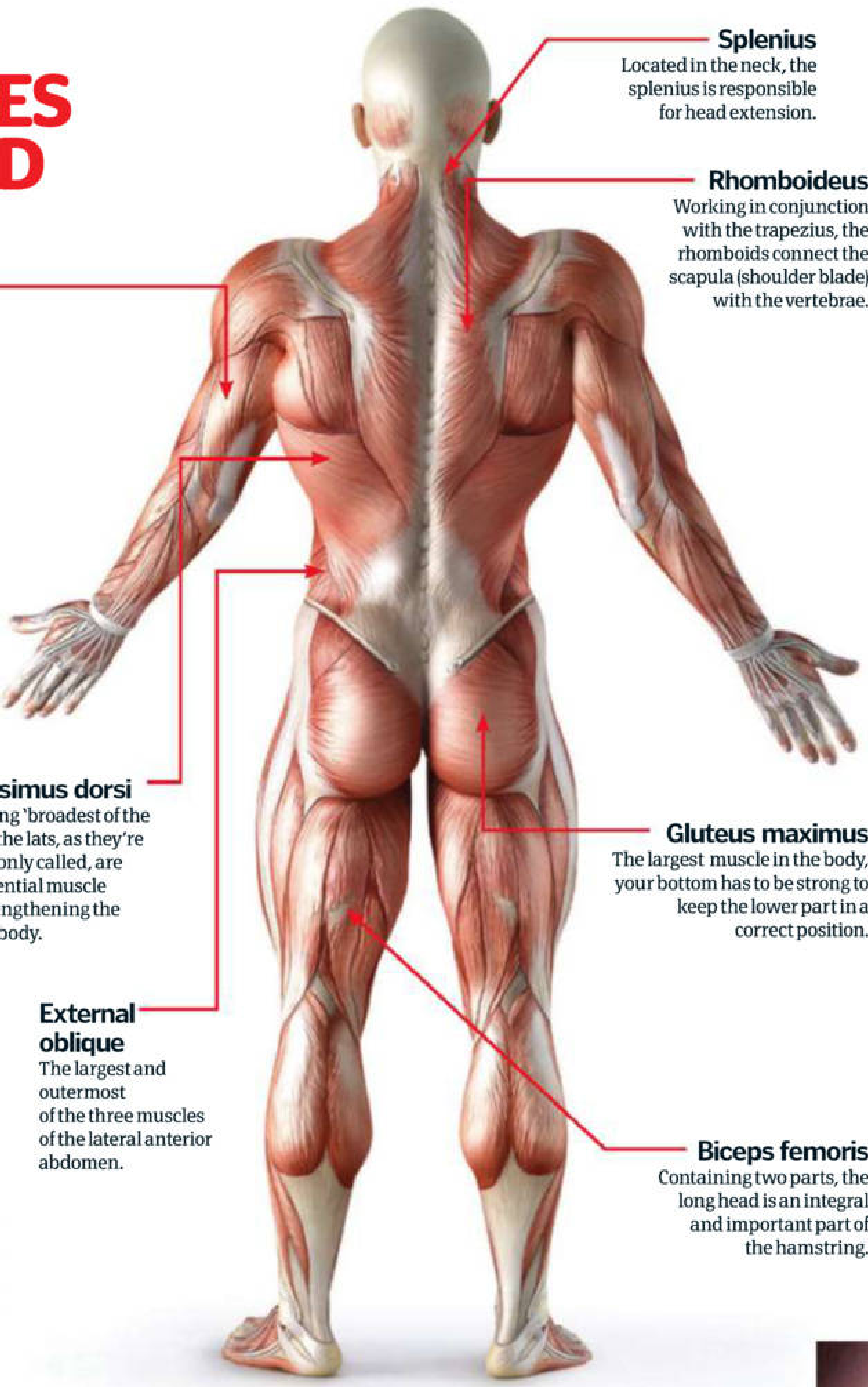
Muscle fibres
This is a skeletal muscle cell and will fall into the mentioned 'type' categories. There can be far more than just types I and II.

Fascicle
A bundle of muscle fibres is known as a fascicle. Surrounded by perimysium – the connective tissues that groups individual fibres together – this collection makes up a muscle.

Actin
Found in muscle tissue, actin is a strand of protein. When this and myosin interlock with each other and pull, it activates the shortening of the myofibril.

Myosin
Myosin is also an important protein strand and reacts first when a muscle contracts, subsequently activating the actin thread.

MUSCLES BEHIND



Splenius
Located in the neck, the splenius is responsible for head extension.

Rhomboideus
Working in conjunction with the trapezius, the rhomboids connect the scapula (shoulder blade) with the vertebrae.

Triceps
As the name suggests there's three parts to the muscle: the long, lateral and medial head.

Latissimus dorsi
Meaning 'broadest of the back', the lats, as they're commonly called, are an essential muscle for strengthening the entire body.

External oblique
The largest and outermost of the three muscles of the lateral anterior abdomen.

Gluteus maximus
The largest muscle in the body, your bottom has to be strong to keep the lower part in a correct position.

Biceps femoris
Containing two parts, the long head is an integral and important part of the hamstring.

Upper arms

Exercise name: Tricep kickback

How to do it: Take one dumbell and hold it by your side. With the elbow locked pointing to the ceiling, extend your arm behind you till it's straight.

Details: Tricep extensions hit the three different heads that make up a large part of the upper arm at once.

STRENGTH RATING: ●●○○○

Hamstrings

Exercise name: Hamstring curls

How to do it: Use a hamstring curl machine and lock legs into position. Push against the foam pad until your legs are at 90° and go back to the start.

Details: Curls will provide extra support to squats, meaning you'll be able to lift more weight from your legs.

STRENGTH RATING: ●○○○○

Back

Exercise name: Deadlift

How to do it: Lay barbell on the floor. Put shins to the bar, bend knees and push from the legs. When bar passes hips, straighten back and stand up.

Details: The deadlift utilises every muscle in your body, from your back to your hamstrings.

STRENGTH RATING: ●●●●●

Quadriceps

Exercise name: Squats

How to do it: Using barbell in a squat rack, place bar on trapezius. Back straight, bend knees until hamstrings parallel with floor. Push from legs.

Details: Squats target all of your leg muscles, as well as most of your upper ones too.

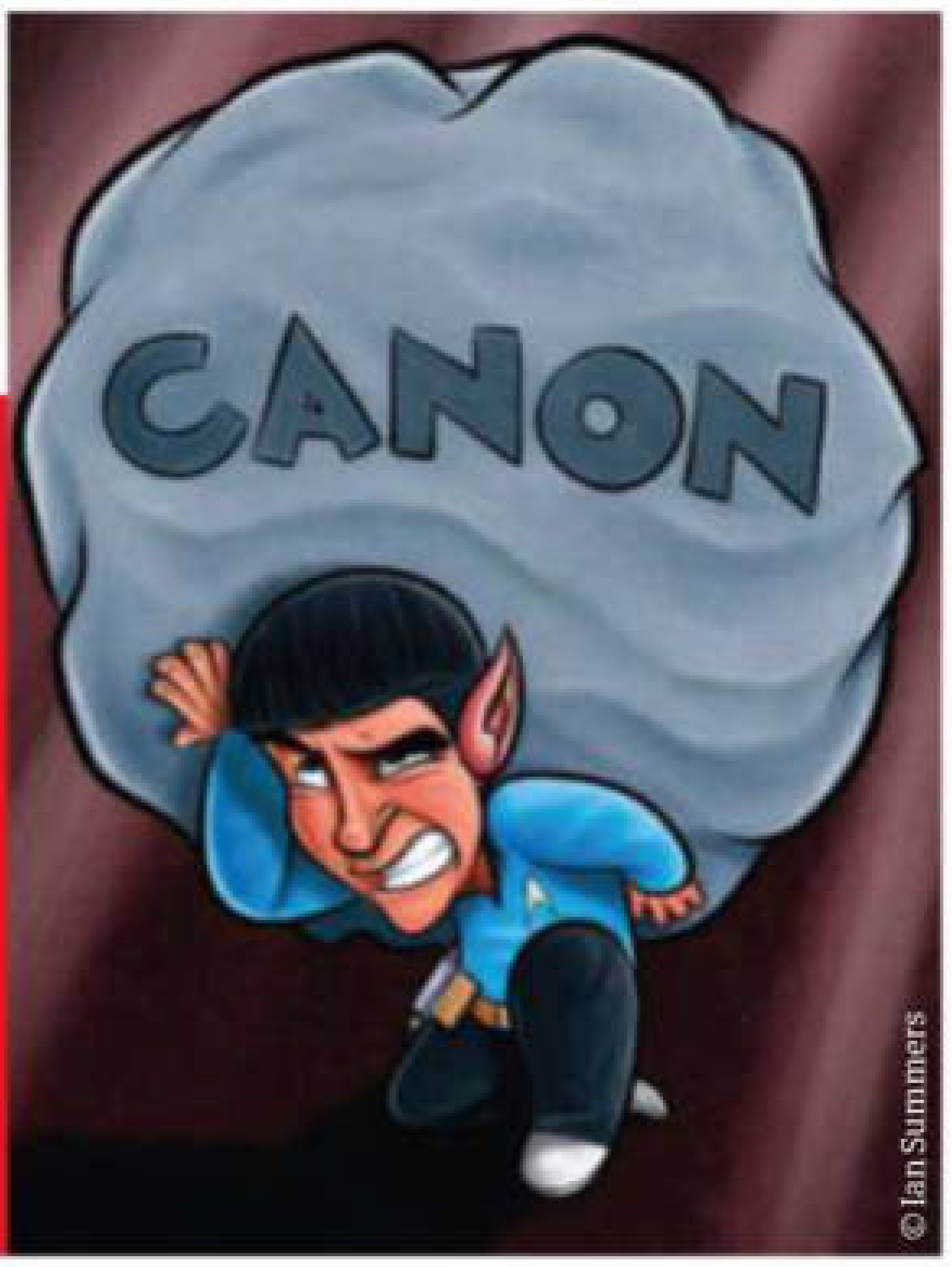
STRENGTH RATING: ●●●●●

Muscle mass corresponds to calories consumed

Hysterical strength – fact or fiction?

Superhuman strength in certain circumstances

Believe it or not, on occasion a desperate mother has found the strength to lift a car in order to save her threatened child. Seems impossible, right? Although there's no scientific evidence to support it, the most common theory is that the rush of adrenaline from the situation increases muscle twitching, enabling the recipient to be stronger and work harder for a very short period of time. When such an event occurs, though, what you don't hear about is the damage and injuries that these heroes usually suffer. It's why the body produces lactic acid in most cases, in order to stop the body from overdoing it and damaging too much muscle fibre.



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What's inside your head?

A look at how our thinking machines are put together

From birth, the head of a baby will grow very rapidly. By the age of two the bones will have fused together, although growth continues until the age of seven during which the shape and size of the skull are altered. An adult human head is made from 22 bones. Eight are present in the cranium, and 14 form the face. Together they make up the skull, which provides a framework for all the features of our heads.

The primary purpose of the skull is to prevent damage to the brain. Without it, even a small force against the head could cause serious brain damage. Before birth, the skull develops holes in which are found the various features of the head.

The skull has three main structural features. Cavities known as orbits contain the eyes, providing protection but also allowing muscles, nerves, blood supply and tissue to reach the eyes. Paranasal sinuses house the nasal cavity and also contain air-filled spaces, which are responsible for making people sound different. Finally, the head is held together by sutures, which are soft fibres at birth but later harden to give the appearance of stitches. They become immovable joints which stop the head falling apart.

The muscles of the head are stretched over the bones in the cranium and face like sheets. There are two main categories of muscles. The muscles of facial expressions are responsible for moving the mouth, altering the chin and moving the cheeks to assist eating and breathing. Muscles of mastication directly control eating, opening and closing the jaw and allow sideways movements. Smaller muscles control other portions of the face including the inner ear and the eye.

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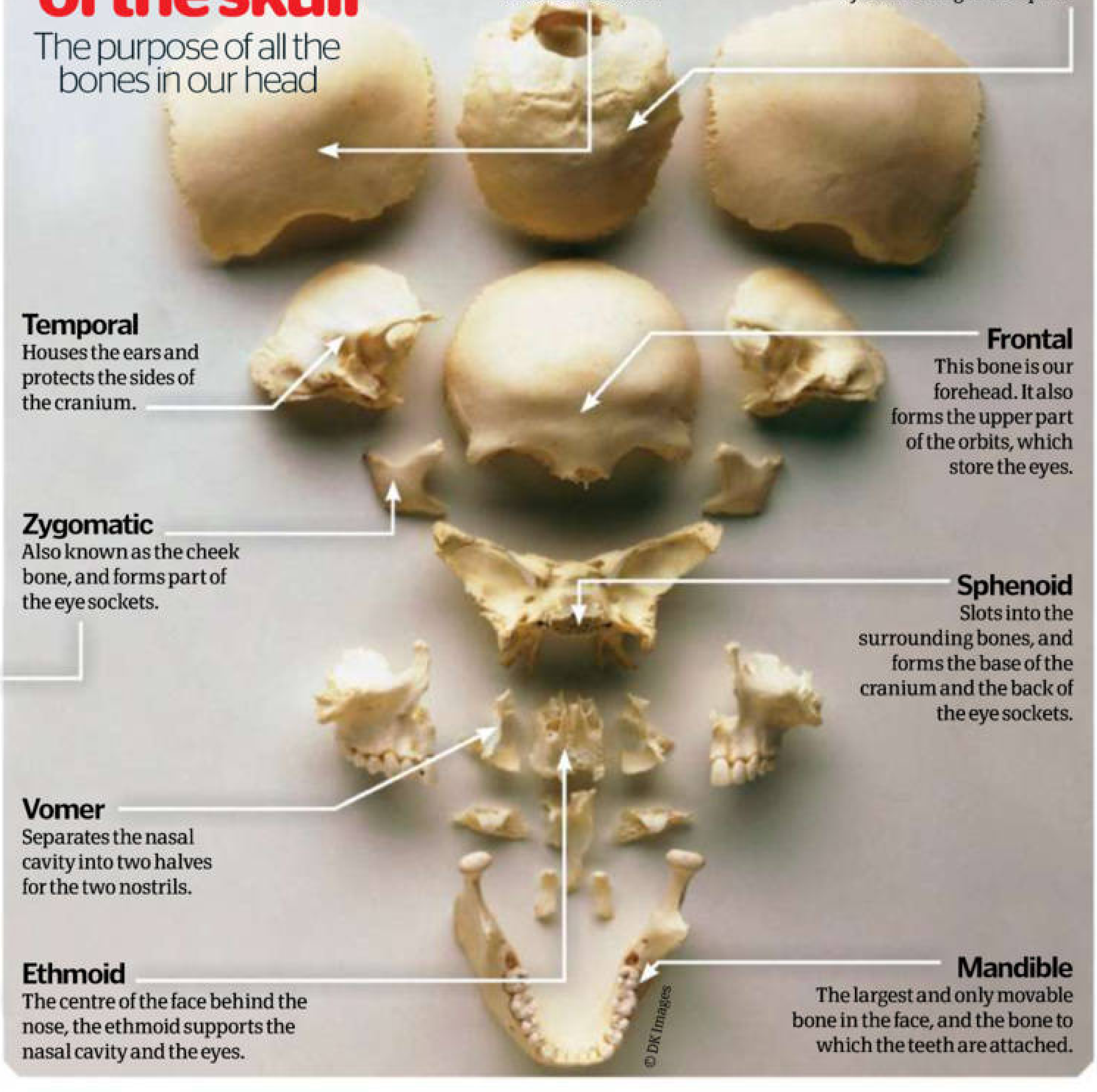
The bones of the skull

The purpose of all the bones in our head



Parietal
Protects the top and sides of the brain, and provides a roof for the skull.

Occipital
Forms the lower back of the skull, and enables movement of the head by connecting to the spine.

Temporal
Houses the ears and protects the sides of the cranium.

Frontal
This bone is our forehead. It also forms the upper part of the orbits, which store the eyes.

Zygomatic
Also known as the cheek bone, and forms part of the eye sockets.

Sphenoid
Slots into the surrounding bones, and forms the base of the cranium and the back of the eye sockets.

Vomer
Separates the nasal cavity into two halves for the two nostrils.

Ethmoid
The centre of the face behind the nose, the ethmoid supports the nasal cavity and the eyes.

Mandible
The largest and only movable bone in the face, and the bone to which the teeth are attached.

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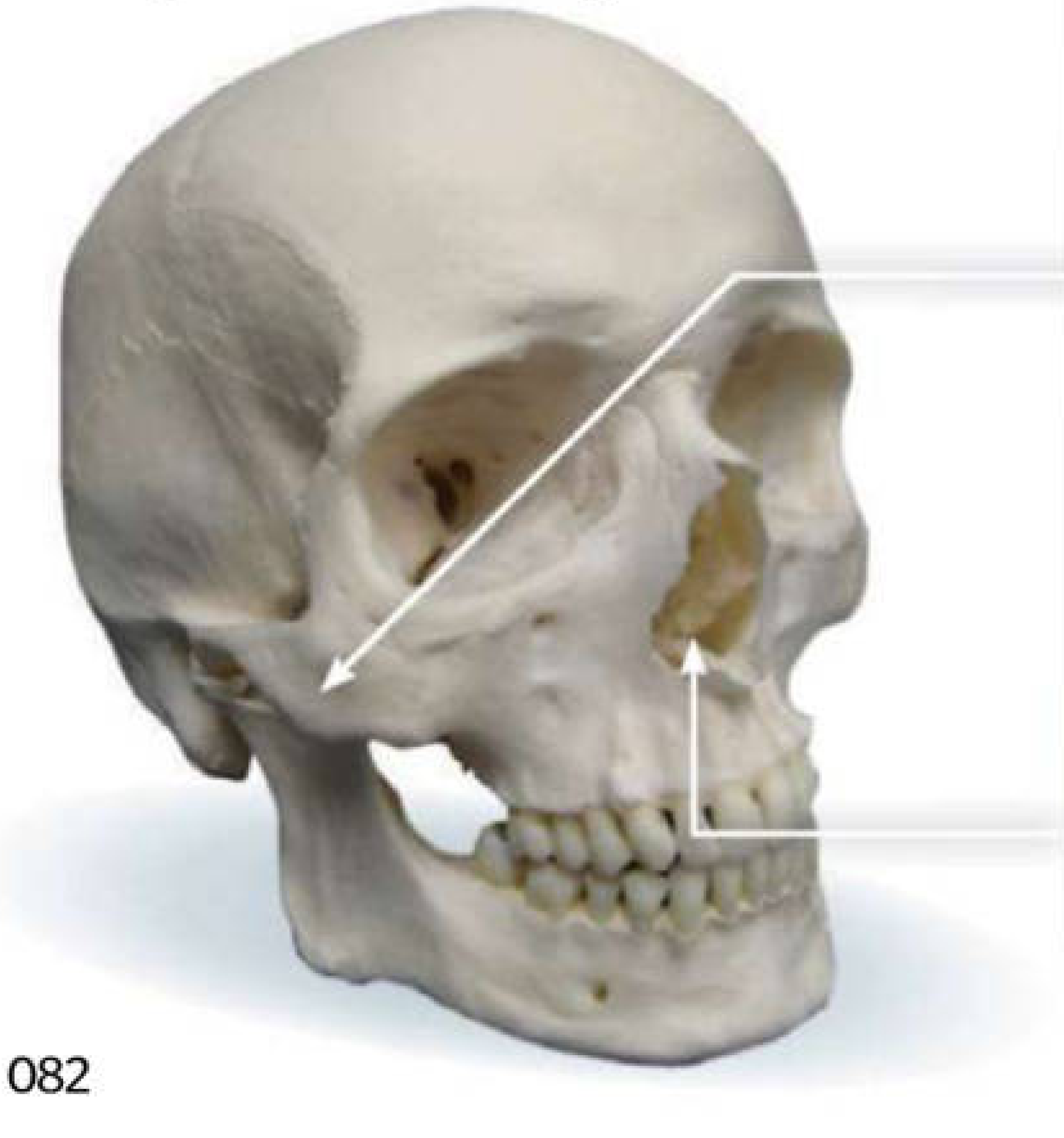
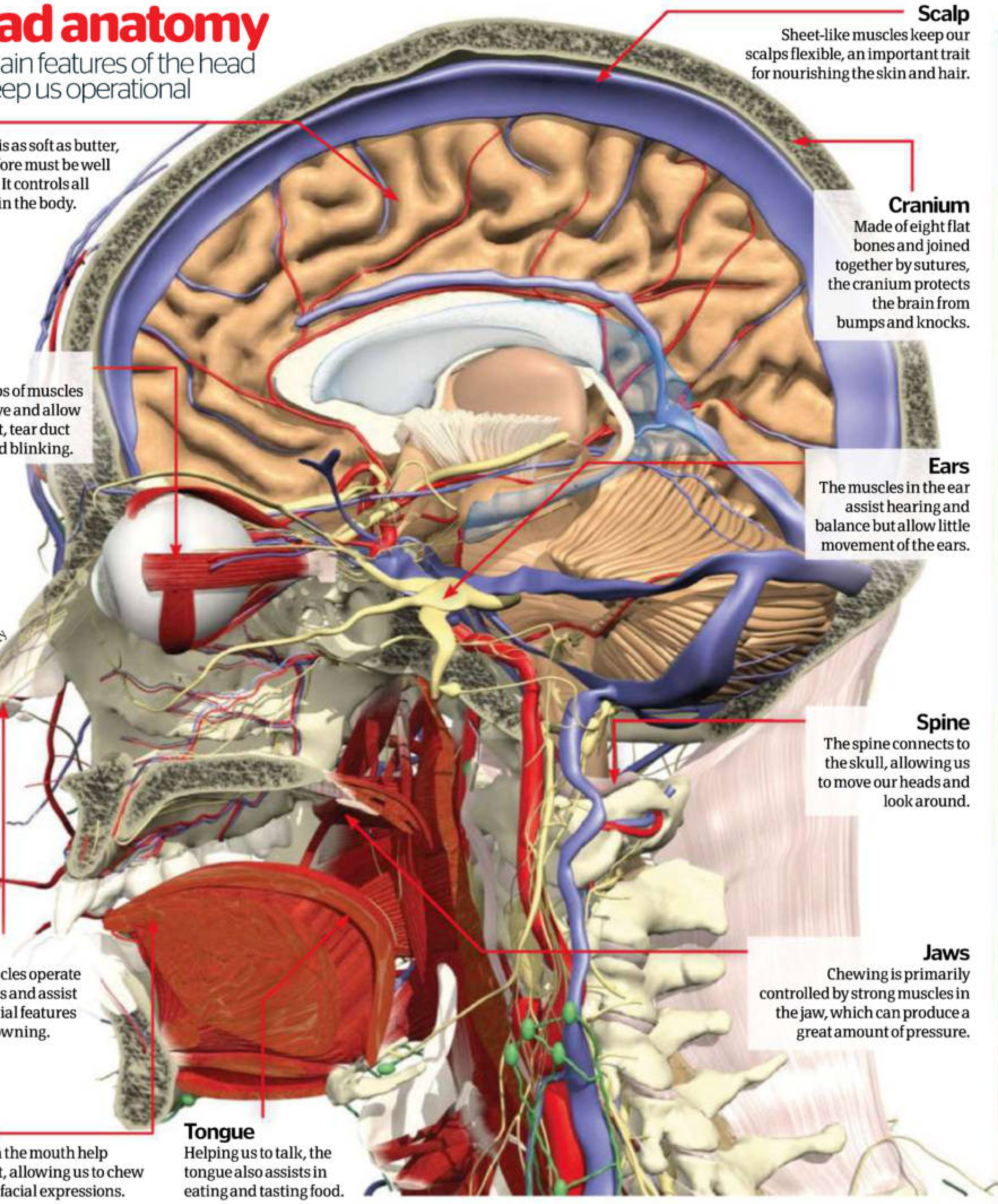


Head anatomy

The main features of the head that keep us operational



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Brain
The brain is as soft as butter, and therefore must be well protected. It controls all functions in the body.

Scalp
Sheet-like muscles keep our scalps flexible, an important trait for nourishing the skin and hair.

Cranium
Made of eight flat bones and joined together by sutures, the cranium protects the brain from bumps and knocks.

Eyes
Two groups of muscles hold the eye and allow movement, tear duct control and blinking.

Ears
The muscles in the ear assist hearing and balance but allow little movement of the ears.

Spine
The spine connects to the skull, allowing us to move our heads and look around.

Nose
Nasal muscles operate the nostrils and assist several facial features such as frowning.

Jaws
Chewing is primarily controlled by strong muscles in the jaw, which can produce a great amount of pressure.

Mouth
Muscles in the mouth help movement, allowing us to chew and make facial expressions.

Tongue
Helping us to talk, the tongue also assists in eating and tasting food.

Your eyes are held in place but with the freedom to move

A strong jaw and teeth allow us to chew and digest food

What's a knockout?

When the head is struck hard enough, a person can become unconscious. This can cause long-lasting head injuries and must be treated immediately. As the head is struck, the brain processes all the information it receives from the sensory nerves to formulate an appropriate response, be it forcing the person to withdraw, pushing their aggressor or holding the injured area. However, the brain also has a limit on how much it can process at any time, and a hard enough blow may overload it with information.

To prevent any further damage to the head, the brain stops communicating with the body, causing unconsciousness. Although it may seem similar to sleep, an unconscious person will not respond to people or noises and will only wake up once the brain begins communicating with the body again.

Head injuries must always be taken very seriously

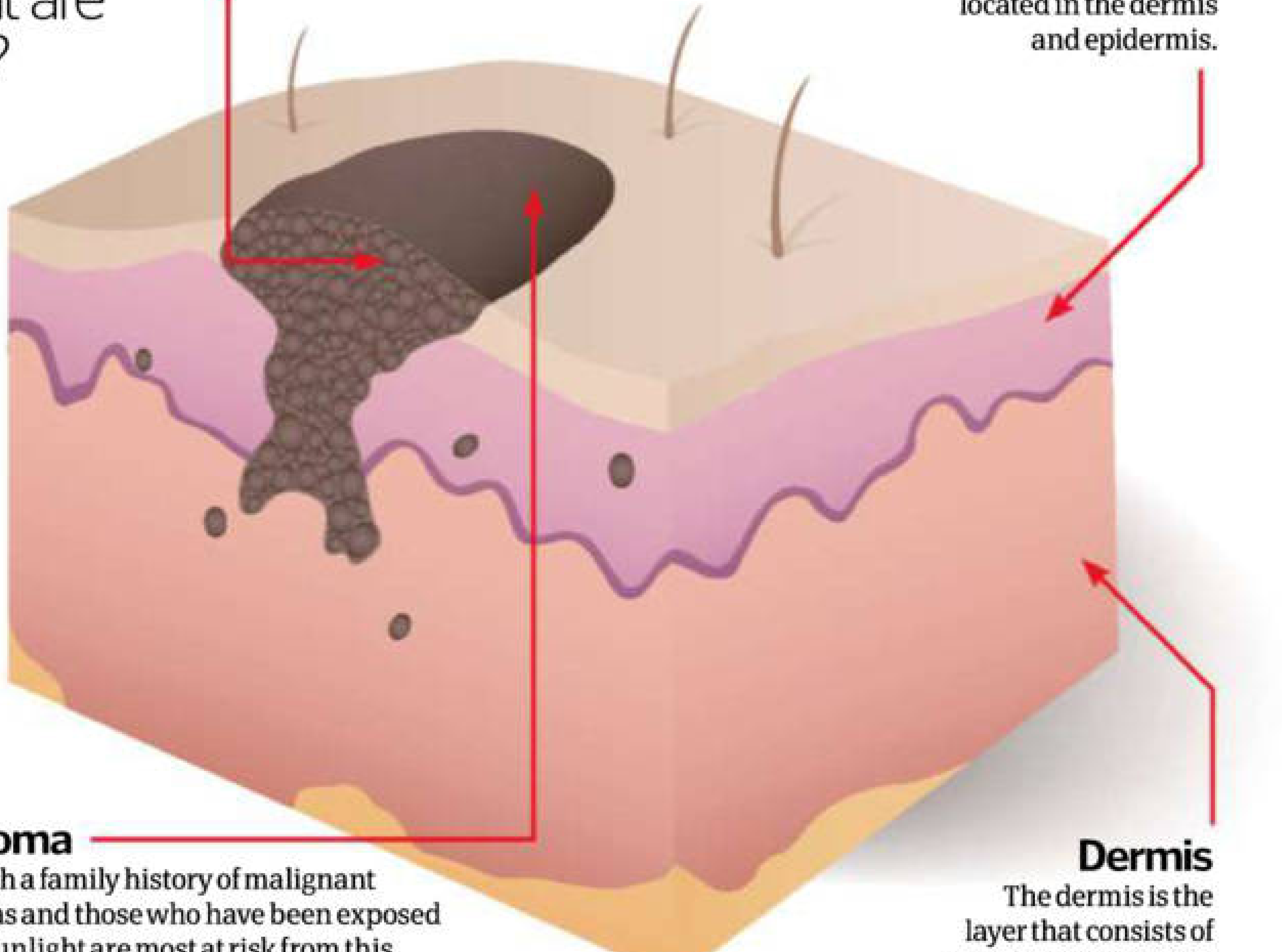
What are moles?

These small skin blemishes are common, but what are they and why must we keep a close eye on them?

A mole on the skin, or a melanocytic naevus, is an abnormal collection of the pigment cells called melanocytes. Some moles can be present at birth (congenital melanocytic naevi) but most develop spontaneously later in life, usually as a result of exposure to sunlight. Moles are often brown or black (pigmented naevi) and are most commonly round or oval, but they can be a variety of different shapes and sizes. Growth and change over time is quite normal.

Moles sound pretty unremarkable and are harmless in nature, and yet we must be vigilant if a new one appears on the skin or if an existing mole begins to change. A malignant melanoma is a rare kind of skin cancer that can occur in melanocytes. Although rare, malignant melanomas cause the majority of the deaths related to skin cancer. If you are particularly moley you're more susceptible to melanoma and should try to avoid too much sunlight.

Moles to watch are dysplastic naevi, which are large, irregularly shaped moles of mixed colouration. They often have paler, jagged edges with darker centres and tend to be accompanied by a lot of other moles on the body.



Melanocyte
The skin's natural pigment, melanin, is a protein produced in cells called melanocytes. Melanocytes are usually spread evenly throughout the skin for even colour. Melanin also absorbs UV radiation.

Epidermis
This is the outer layer of your skin and it contains tough, flat cells. Melanocytes are located in the dermis and epidermis.

Melanoma
People with a family history of malignant melanomas and those who have been exposed to a lot of sunlight are most at risk from this uncontrollable growth of pigment cells.

Dermis
The dermis is the layer that consists of blood vessels, glands and nerve endings.

Why do we get spots?

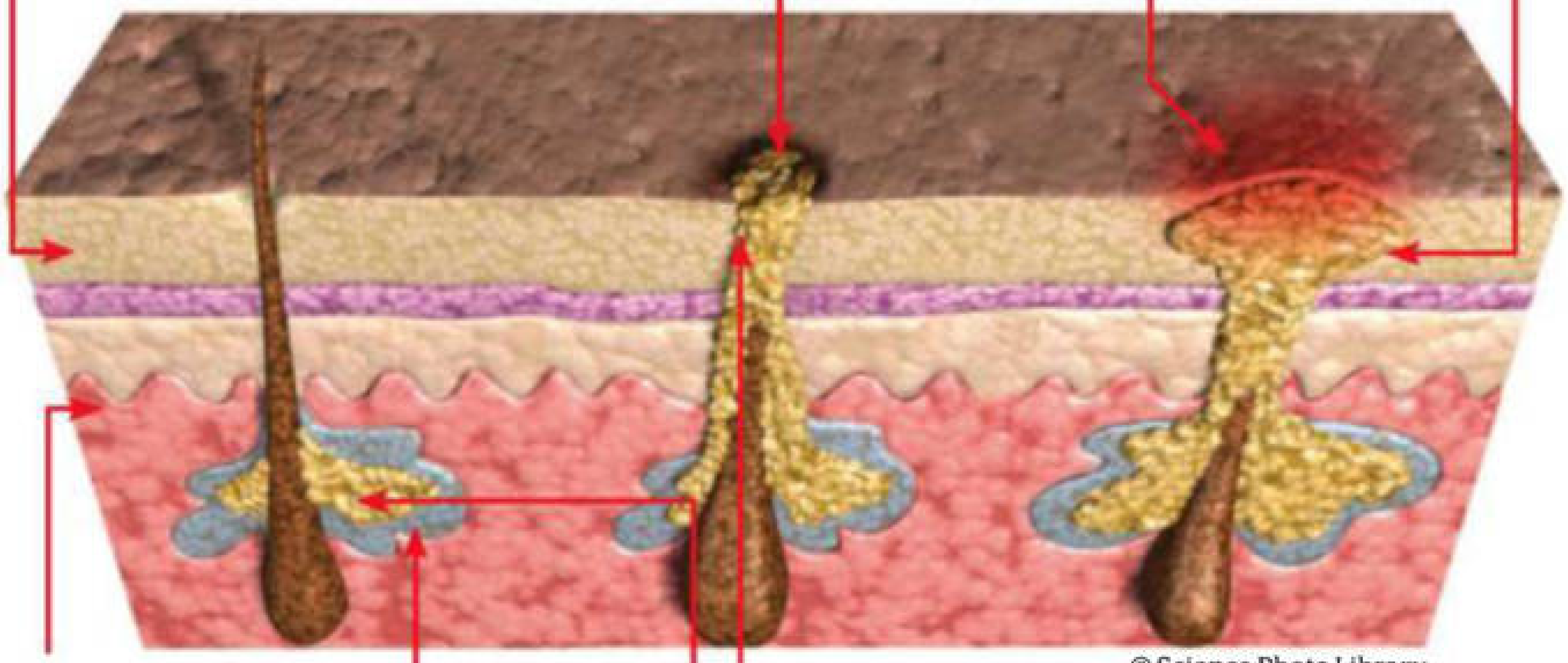
Find out what causes pimples to form on the surface of human skin

Pimples are caused by sensitivity to the testosterone hormone present in both males and females, which can trigger the overproduction of an oily substance called sebum. Sebum, which is produced by sebaceous glands attached to hair follicles in the dermis, helps keep hair and skin waterproof.

Your skin is constantly renewing itself, and while new cells are produced in the lower layers of skin, the old dead cells are sloughed away from the surface. This, together with excessive sebum production, can lead to acne and pimples.

Sebum normally travels through the hair follicle to the surface of the skin. However, if a pore becomes blocked by a few dead skin cells that haven't been shed properly, the sebum can begin to build up inside the hair follicle. This oily buildup is the perfect breeding ground for bacteria, which then accumulate and multiply around the area, making the skin inflamed and infected. This results in the pimple.

Whiteheads and blackheads are types of acne pimples known as comedones. Blackheads are open comedones, which means the blockage of sebum is exposed to the air, causing oxidation of the sebum (like when an apple browns). Whiteheads, on the other hand, are closed comedones and are not exposed to air as they're covered by a layer of skin.



Inflammation
The trapped sebum attracts bacteria that build up and cause a pustule, which can grow inflamed.

Blackhead
When the blockage is nearer the surface, the accumulation of sebum can be exposed to the air, causing oxidation which turns the substance black.

Whitehead
Blockages can occur beneath a layer of skin that prevents air from coming into contact with the sebum which results in it staying white.

Epidermis
Sebum helps slough away the cells on the surface of the skin as they die to make room for the fresh cells generated in the dermis.

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Dermis
New skin cells are created in the lower layers of skin.

Sebaceous gland
Attached to the hair follicle, the sebaceous gland produces an oily, waxy substance called sebum.

Sebum
The sebum travels up the hair follicle to waterproof the hair and protect the surface of the skin.

Blockage
If dead skin cells fail to be shed properly, they can become blocked inside pores. When this happens sebum is plugged behind a barrier, which can lead to a spot forming.

What are tonsils for?

What purpose do these fleshy lumps in the back of our throats serve?

Tonsils are the small masses of flesh found in pairs at the back of the throats of many mammals. In humans the word is actually used to describe three sets of this spongy lymphatic tissue: the lingual tonsils, the pharyngeal tonsils and the more commonly recognised palatine tonsils.

The palatine tonsils are the oval bits that hang down from either side at the back of your throat – you can see them if you open your mouth wide in the mirror. Although the full purpose of the palatine tonsils isn't yet understood, because they produce antibodies and because of their prominent position in the throat, they're thought to be the first line of defence against potential infection in both the respiratory and digestive tracts.

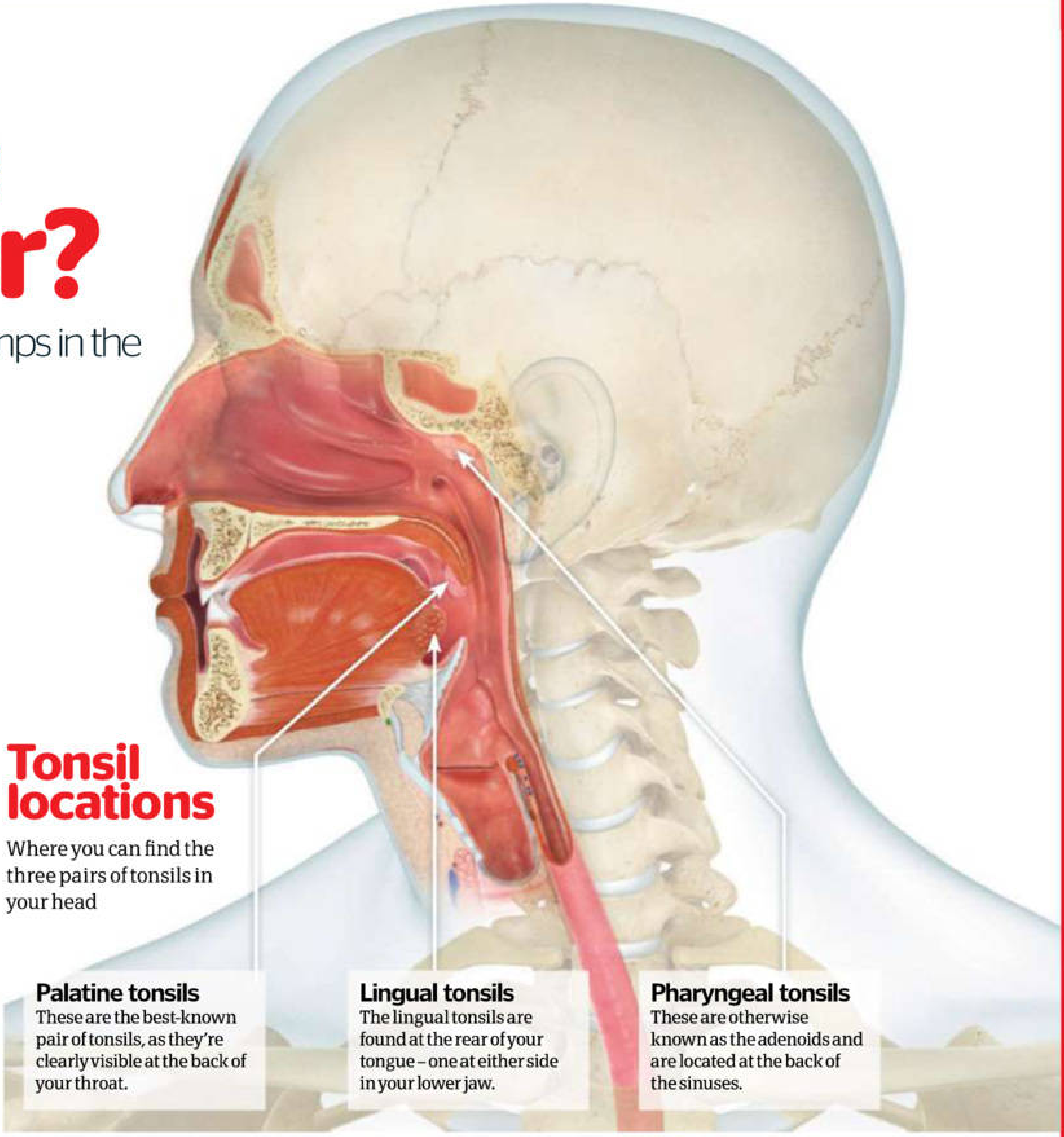
The pharyngeal tonsils are also known as the adenoids. These are found tucked away in the nasal pharynx and serve a similar purpose to the palatine tonsils but shrink in adulthood.

Finally, the lingual tonsils are found at the back of the tongue towards the root where it attaches and, if you poke your tongue right out, you should be able to spot them if you look in the mirror. These are drained very efficiently by mucous glands and, as a result, they very rarely get infected.

"Thought to be the first line of defence against infection"

Tonsil locations

Where you can find the three pairs of tonsils in your head



Palatine tonsils
These are the best-known pair of tonsils, as they're clearly visible at the back of your throat.

Lingual tonsils
The lingual tonsils are found at the rear of your tongue – one at either side in your lower jaw.

Pharyngeal tonsils
These are otherwise known as the adenoids and are located at the back of the sinuses.

Tonsillitis in focus

Lots of bed rest, fluids and pain relief like paracetamol are all recommended for treating tonsillitis

Tonsillitis is usually caused by certain bacteria (eg group A beta-haemolytic streptococci) and sometimes viral infections that result in a sore and swollen throat, a fever, white spots at the back of the throat and difficulty swallowing. Usually rest and antibiotics will see it off, but occasionally the infection is more severe and can cause serious problems, or reoccurs frequently. In these cases a tonsillectomy may be advised – a surgical procedure to remove the tonsils.

The adenoids are less commonly infected but, when they are, can become inflamed and swell to obstruct breathing through the nose and drainage from the sinuses, which can lead to further infections. In young people, constant breathing through the mouth can stress the facial bones and cause deformities, so children will sometimes have their adenoid glands removed.

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The sensory system

The complex senses of the human body and how they interact is vital to the way we live day to day

The sensory system is what enables us to experience the world. It can also warn us of danger, trigger memories and protect us from damaging stimuli, such as scorching hot surfaces. The human sensory system is highly developed, with its many components detecting both physical and emotional properties of the environment. For example, it can interpret chemical molecules in the air into smells, moving molecules of sound into noises and pressure placed on the skin into touch. Indeed, some of our senses are so finely tuned they allow reactions within milliseconds of detecting a new sensation.

The five classic senses are sight, hearing, smell, taste and touch. We need senses not only to interpret the world around us, but also to function within it. Our senses enable us to modify our movements and thoughts, and sometimes they directly feed signals into muscles. The sensory nervous system that lies behind this is made up of receptors, nerves and dedicated parts of the brain.

There are thousands of different stimuli that can trigger our senses, including light, heat, chemicals in food and pressure. These 'stimulus modalities' are then detected by specialised receptors, which convert them into sensations such as hot and cold, tastes, images and touch. The incredible receptors – like the eyes, ears, nose, tongue and skin – have adapted over time to work seamlessly together and without having to be actively 'switched on'.

However, sometimes the sensory system can go wrong. There are hundreds of diseases of the senses, which can have both minor effects, or a life-changing impact. For example, a blocked ear can affect your balance, or a cold your ability to smell – but these things don't last for long.

In contrast, say, after a car accident severing the spinal cord, the damage can be permanent. There are some very specific problems that the sensory system can bring as well. After an amputation, the brain can still detect signals from the nerves that used to connect to the lost limb. These sensations can cause excruciating pain; this particular condition is known as phantom limb syndrome.

However the sensory system is able to adapt to change, with the loss of one often leading to others being heightened. Our senses normally function to gently inhibit each other in order to moderate individual sensations. The loss of sight from blindness is thought to lead to strengthening of signals from the ears, nose and tongue. Having said this, it's certainly not universal among the blind, being more common in people who have been blind since a young age or from birth. Similarly, some people who listen to music like to close their eyes, as they claim the loss of visual input can enhance the audio experience.

Although the human sensory system is well developed, many animals out-perform us. For example, dogs can hear much higher-pitched sounds, while sharks have a far better sense of smell – in fact, they can sniff out a single drop of blood in a million drops of water!

Ears feed sounds to the brain but also control balance

About 100 million photoreceptors per eye

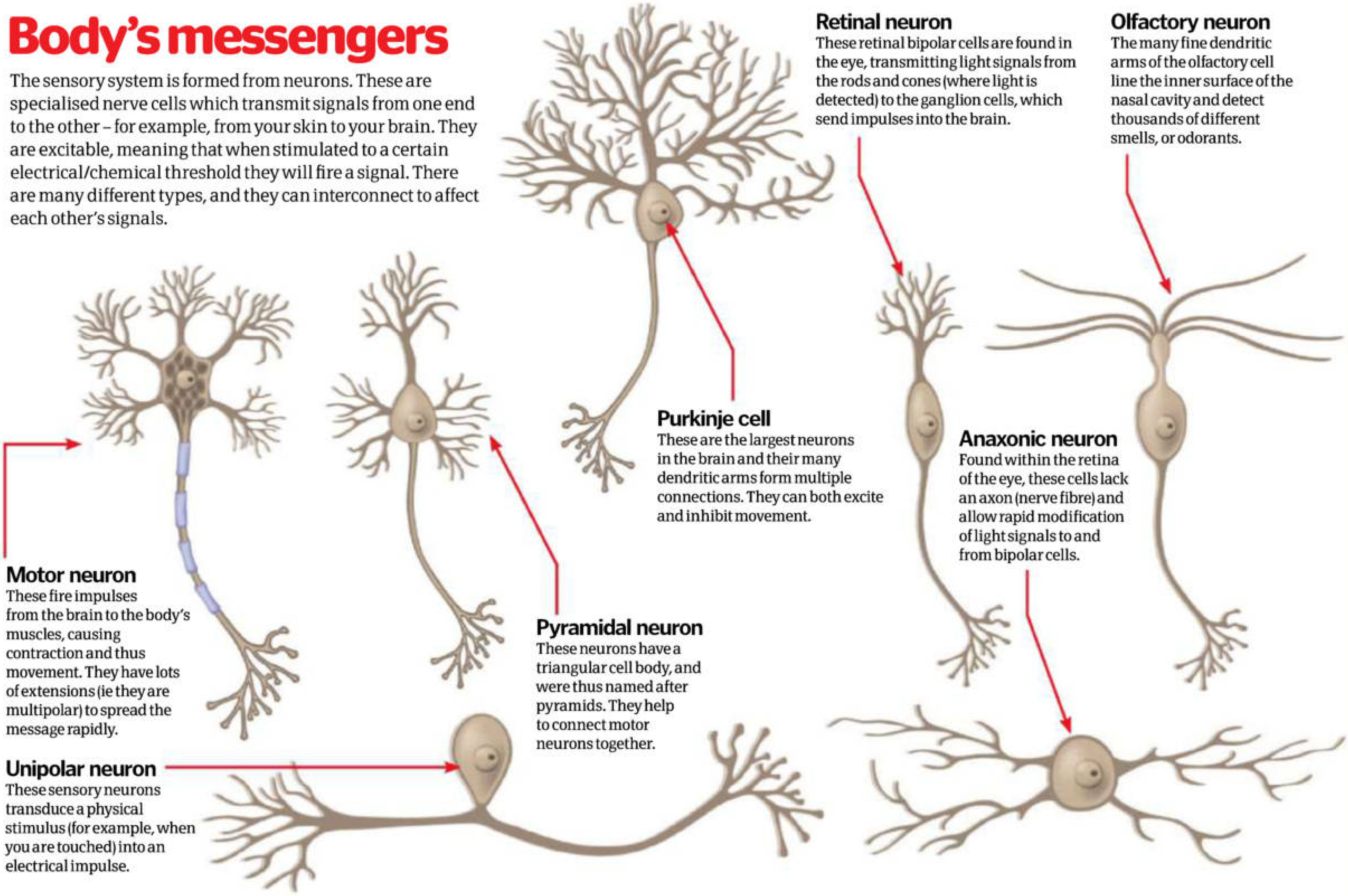
9,000 taste buds over the tongue and throat

We can process over 10,000 different smells

Touch is the first sense to develop in the womb

Body's messengers

The sensory system is formed from neurons. These are specialised nerve cells which transmit signals from one end to the other – for example, from your skin to your brain. They are excitable, meaning that when stimulated to a certain electrical/chemical threshold they will fire a signal. There are many different types, and they can interconnect to affect each other's signals.



Retinal neuron
These retinal bipolar cells are found in the eye, transmitting light signals from the rods and cones (where light is detected) to the ganglion cells, which send impulses into the brain.

Olfactory neuron
The many fine dendritic arms of the olfactory cell line the inner surface of the nasal cavity and detect thousands of different smells, or odorants.

Purkinje cell
These are the largest neurons in the brain and their many dendritic arms form multiple connections. They can both excite and inhibit movement.

Anaxonic neuron
Found within the retina of the eye, these cells lack an axon (nerve fibre) and allow rapid modification of light signals to and from bipolar cells.

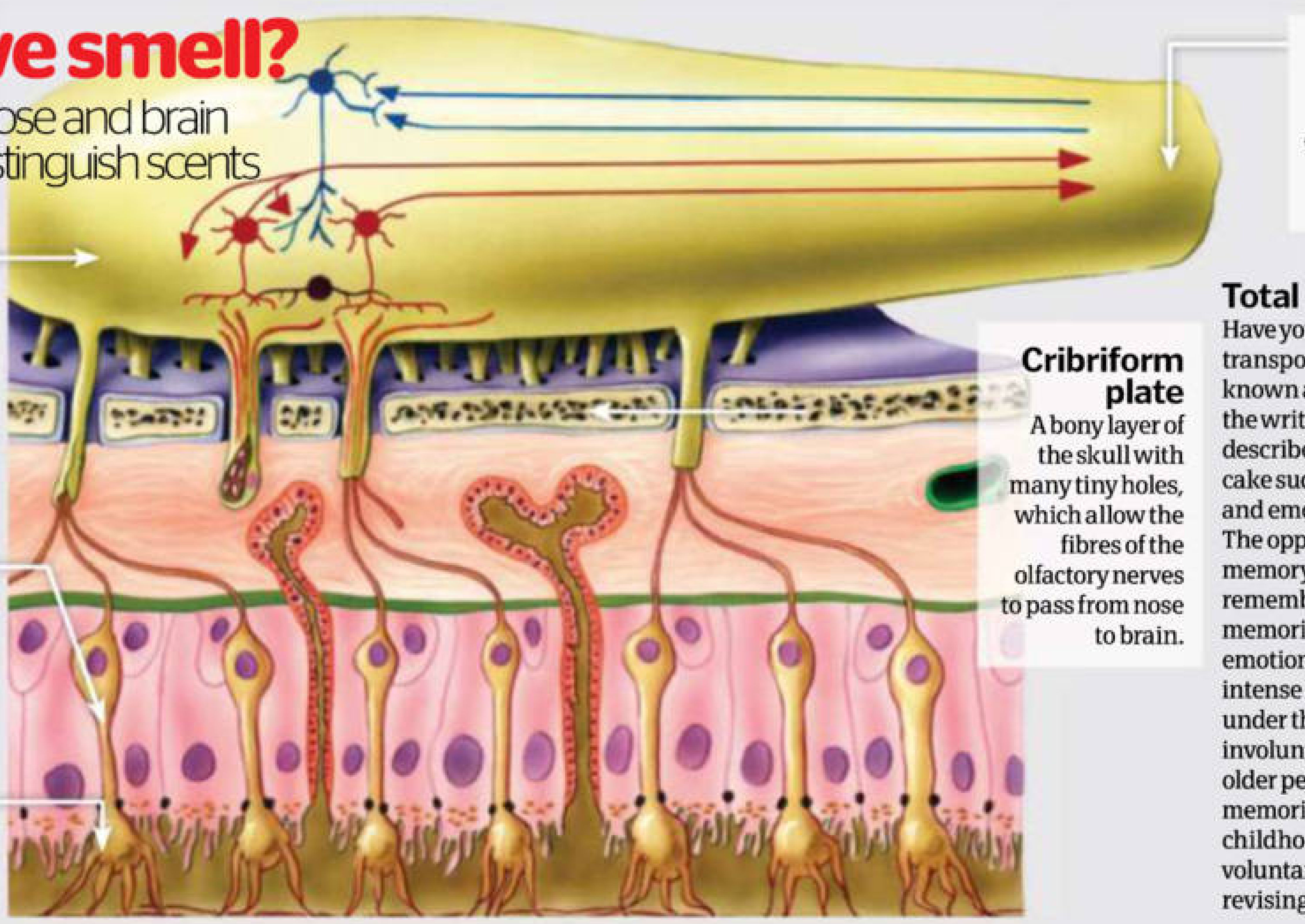
Motor neuron
These fire impulses from the brain to the body's muscles, causing contraction and thus movement. They have lots of extensions (ie they are multipolar) to spread the message rapidly.

Pyramidal neuron
These neurons have a triangular cell body, and were thus named after pyramids. They help to connect motor neurons together.

Unipolar neuron
These sensory neurons transduce a physical stimulus (for example, when you are touched) into an electrical impulse.

How do we smell?

Find out how our nose and brain work together to distinguish scents



Olfactory bulb
Containing many types of cell, olfactory neurons branch out of here through the cribriform plate below.

Olfactory neuron
These neurons are highly adapted to detect a wide range of different odours.

Olfactory epithelium
Lining the nasal cavity, this layer contains the long extensions of the olfactory neurons and is where chemical molecules in air trigger an electric impulse.

Cribriform plate
A bony layer of the skull with many tiny holes, which allow the fibres of the olfactory nerves to pass from nose to brain.

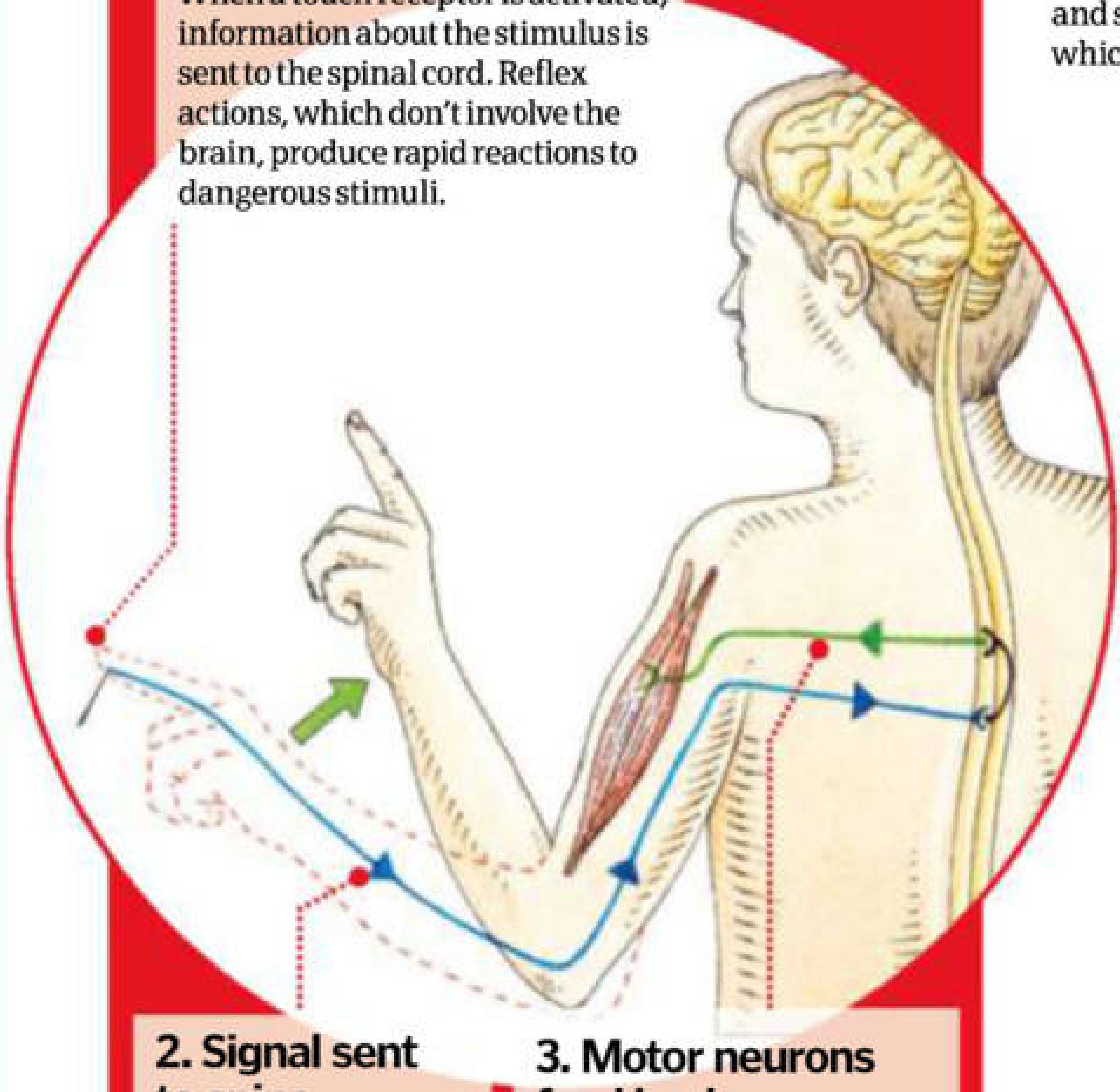
Olfactory nerve
New signals are rapidly transmitted via the olfactory nerve to the brain, which collates the data with sight and taste.

Total recall
Have you ever smelt something that transported you back in time? This is known as the Madeleine effect because the writer Marcel Proust once described how the scent of a madeleine cake suddenly evoked strong memories and emotions from his childhood. The opposite type of recall is voluntary memory, where you actively try and remember a certain event. Involuntary memories are intertwined with emotion and so are often the more intense of the two. Younger children under the age of ten have stronger involuntary memory capabilities than older people, which is why these memories thrust you back to childhood. Older children use voluntary memory more often, eg when revising for exams.

Understanding lightning reflexes

Have you ever felt something scorching hot or freezing cold, and pulled your hand away without even thinking about it? This reaction is called a reflex. Your reflexes are the most vital and the fastest of all your senses. They are carried out by the many 'reflex arcs' located throughout the body.

For example, a temperature-detecting nerve in your finger connects to a motor nerve in your spine, which travels straight to your biceps, creating a circular arc of nerves. By only having two nerves in the circuit, the speed of the reflex is as fast as possible. A third nerve transmits the sensation to the brain, so you know what's happened, but this nerve doesn't interfere with the arc; it's for your information only. There are other reflex arcs located within your joints, so that, say, if your knee gives way or you suddenly lose balance, you can compensate quickly.



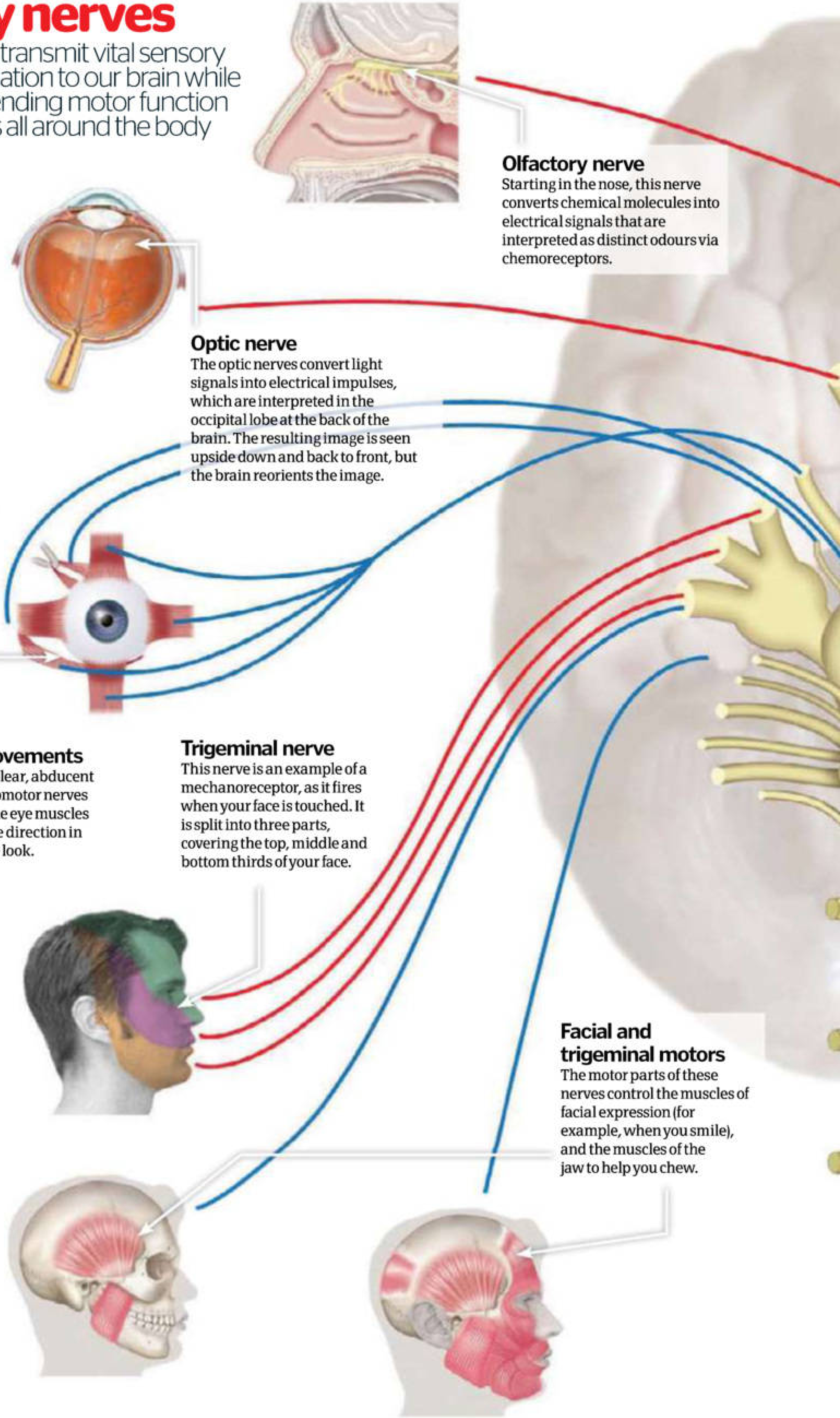
1. Touch receptor
When a touch receptor is activated, information about the stimulus is sent to the spinal cord. Reflex actions, which don't involve the brain, produce rapid reactions to dangerous stimuli.

2. Signal sent to spine
When sensory nerve endings fire, information passes through nerve fibres to the spinal cord.

3. Motor neurons feed back
The signals trigger motor neurons that initiate their own impulses that feed back to the muscle, telling it to move the body part.

Key nerves

These transmit vital sensory information to our brain while also sending motor function signals all around the body



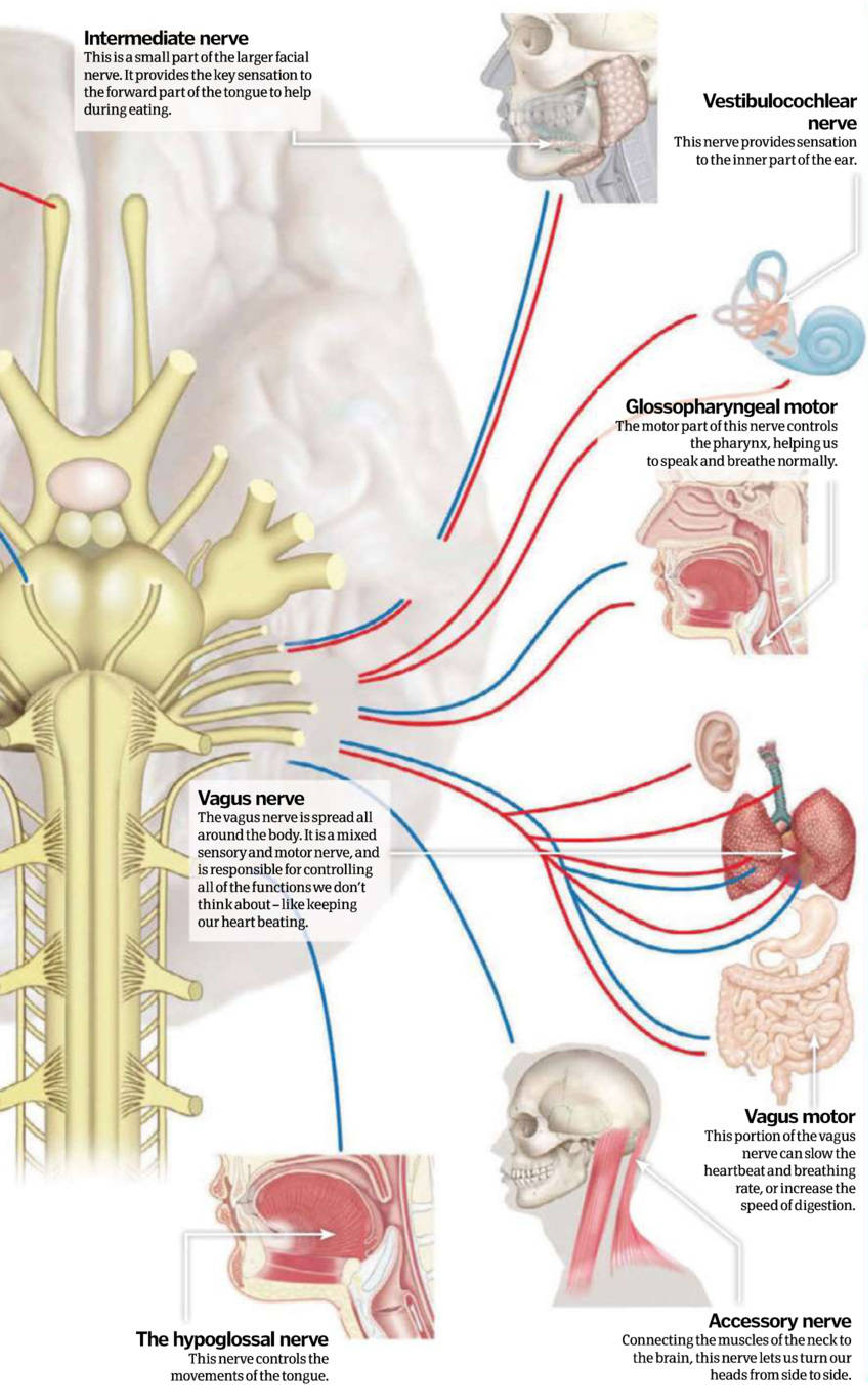
Olfactory nerve
Starting in the nose, this nerve converts chemical molecules into electrical signals that are interpreted as distinct odours via chemoreceptors.

Optic nerve
The optic nerves convert light signals into electrical impulses, which are interpreted in the occipital lobe at the back of the brain. The resulting image is seen upside down and back to front, but the brain reorients the image.

Eye movements
The trochlear, abducent and oculomotor nerves control the eye muscles and so the direction in which we look.

Trigeminal nerve
This nerve is an example of a mechanoreceptor, as it fires when your face is touched. It is split into three parts, covering the top, middle and bottom thirds of your face.

Facial and trigeminal motors
The motor parts of these nerves control the muscles of facial expression (for example, when you smile), and the muscles of the jaw to help you chew.



Intermediate nerve
This is a small part of the larger facial nerve. It provides the key sensation to the forward part of the tongue to help during eating.

Vestibulocochlear nerve
This nerve provides sensation to the inner part of the ear.

Glossopharyngeal motor
The motor part of this nerve controls the pharynx, helping us to speak and breathe normally.

Vagus nerve
The vagus nerve is spread all around the body. It is a mixed sensory and motor nerve, and is responsible for controlling all of the functions we don't think about – like keeping our heart beating.

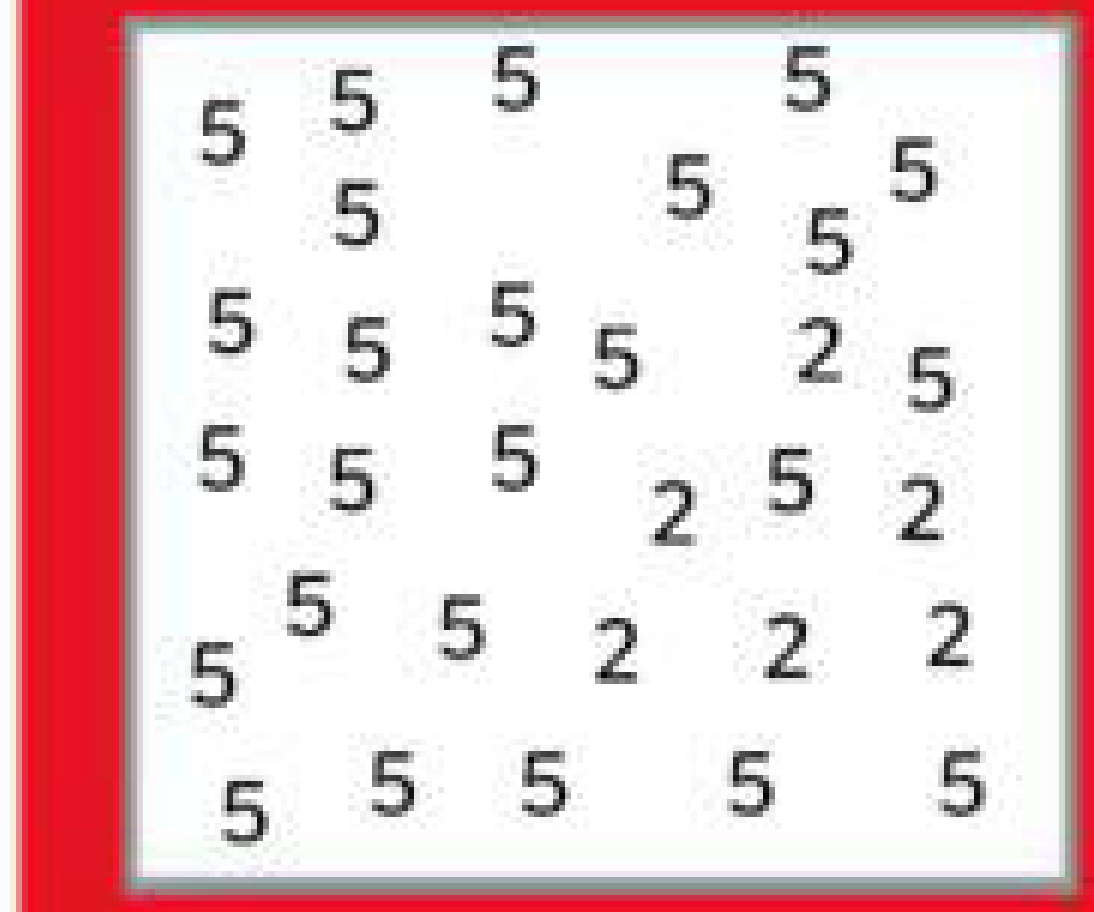
Vagus motor
This portion of the vagus nerve can slow the heartbeat and breathing rate, or increase the speed of digestion.

The hypoglossal nerve
This nerve controls the movements of the tongue.

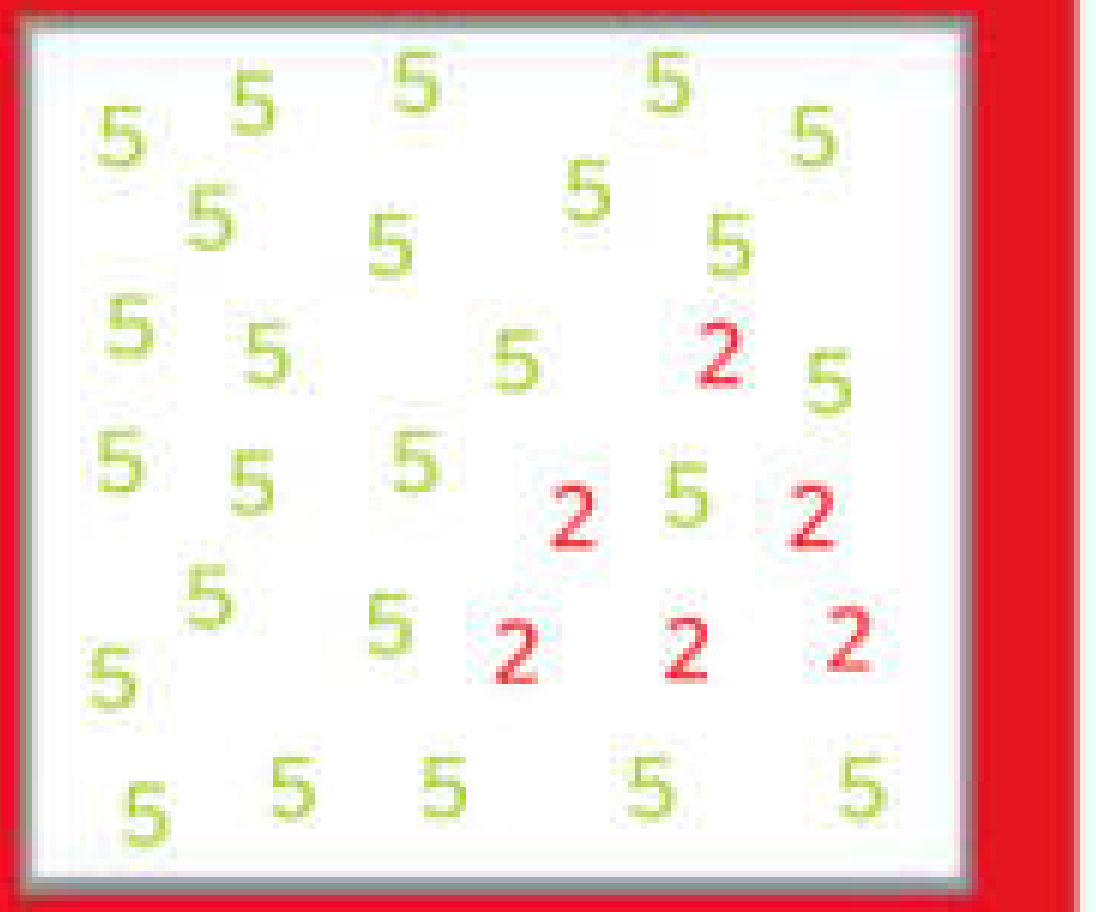
Accessory nerve
Connecting the muscles of the neck to the brain, this nerve lets us turn our heads from side to side.

Crossed senses

Synaesthesia is a fascinating, if not entirely understood, condition. In some people, two or more of the five senses become linked so when a single sensation is triggered, all the linked sensations are activated too. For example, the letter 'A' might always appear red for that person, or seeing the number '1' might trigger the taste of apples. Sights take on smells, a conversation can have a tastes and music can feel textured. People with synaesthesia certainly don't consider it to be a disorder or disease. In fact, many do not consider it unusual at all, and couldn't imagine living without it. It often runs in families and may be more common than we think.



Non-synaesthetes struggle to identify a triangle of 2s among a field of number 5s.



But a synaesthete who sees 2s as red and 5s as green can quickly pick out the triangle.

A patient's sense of proprioception is being put to the test here

Is there really a 'sixth sense'?

Our sense of balance and the position of our bodies in space are sensations we rarely think about and so are sometimes thought of as a 'sixth sense'. There is a whole science behind them though, and they are collectively called proprioception. There are nerves located throughout the musculoskeletal system (for example, within your muscles, tendons, ligaments and joints) who send information on balance and posture back to the brain. The brain then interprets this information rapidly and sends instructions back to the muscles to allow for fine adjustments in balance. Since you don't have to think about it and you can't switch it off, you don't know how vital these systems are until they're damaged. Sadly some medical conditions, including strokes, can affect our sense of proprioception, making it difficult to stand, walk, talk and move our limbs.

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What are fossils? p126

What's in the atmosphere? p114

What is a rainforest? p100

Planet

92 The Earth's structure
Take a look at the molten world hidden beneath our feet

94 25 facts about earthquakes
Find out how earthquakes happen when two pieces of crust meet each other

98 Whitewater rapids
How this part of a river's course provides dangerously turbulent water

99 Rogue waves
The theory behind these freakishly huge waves out at sea

99 Vegetable sheep
These remarkable New Zealand plants resemble flocks of sheep

100 Explaining rainforest
Take look inside these amazing forests and what lives in them

104 How plants work
The life cycle of a plant and how it survives explained

108 How rivers work
A breakdown of the river system, from mountain streams to river mouths

110 Avalanche!
The deadly mountain snow slides explored in detail

111 Icebergs explained
Uncovering what you don't see below the surface

111 Hailstones
How crystals of ice form in the sky and fall from the sky

112 The water cycle
From a cloud to the ground and then back up again, how water works

Where can I find lightning? p119

How are rivers formed? p108

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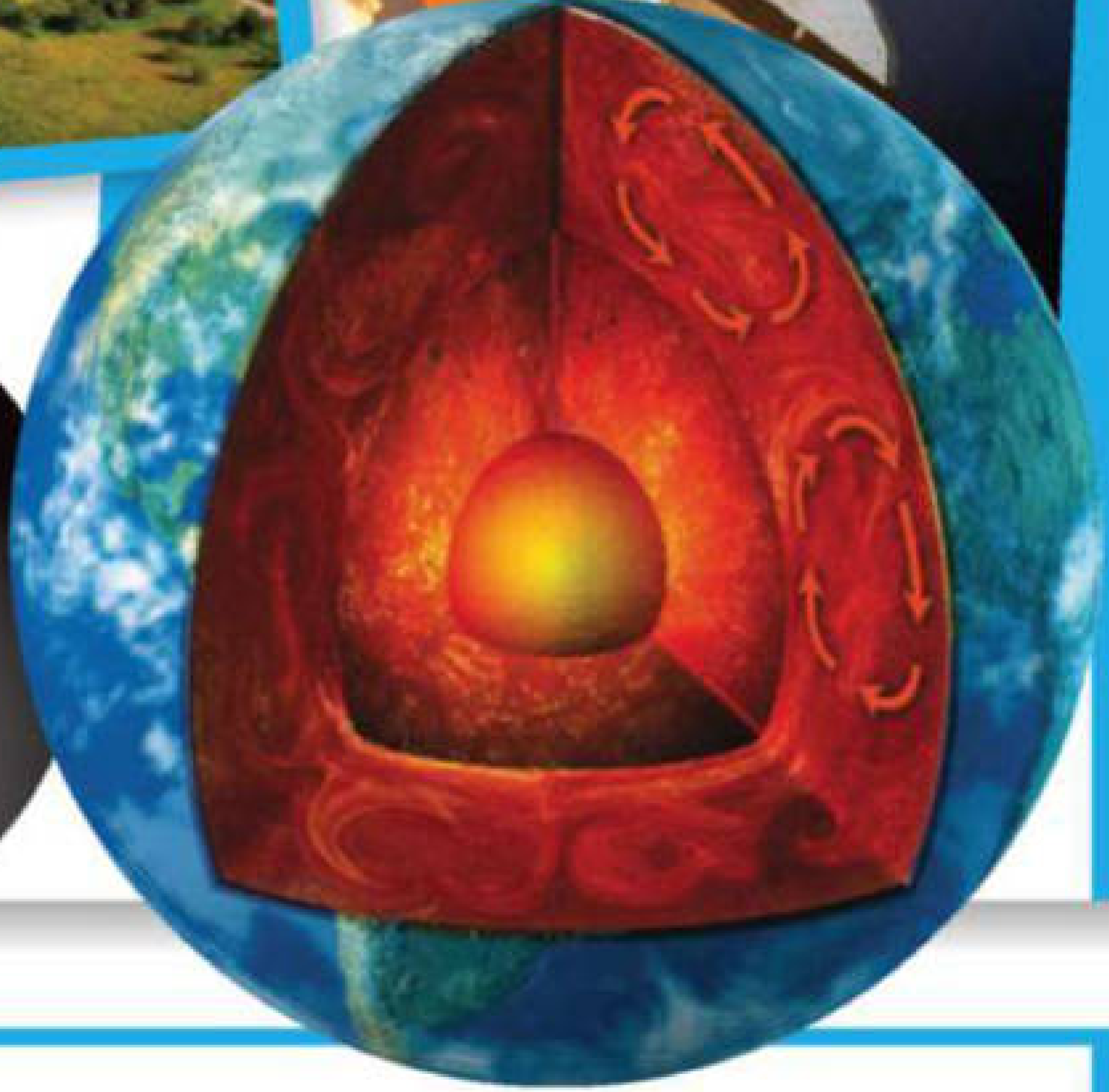

Earth

114 The Earth's atmosphere
Explaining the atmospheric layers that surround and protect us

116 Predicting the weather
The forecasts that tell us whether to wrap up warm

118 50 amazing facts about weather
From fluffy clouds to hurricanes, we delve into nature's weather systems

124 The carbon cycle
It's all around us and the basis of life on Earth, but what does it do?

126 What are fossils?
A long, hard look at the past

130 Earth's minerals
How the treasures of our planet are formed in the Earth's crust

132 Super volcanoes
See the deadliest magma throwers in the world up close

What is the Japan Trench? p97

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The Earth's

We take an in-depth look at the hidden world beneath our feet

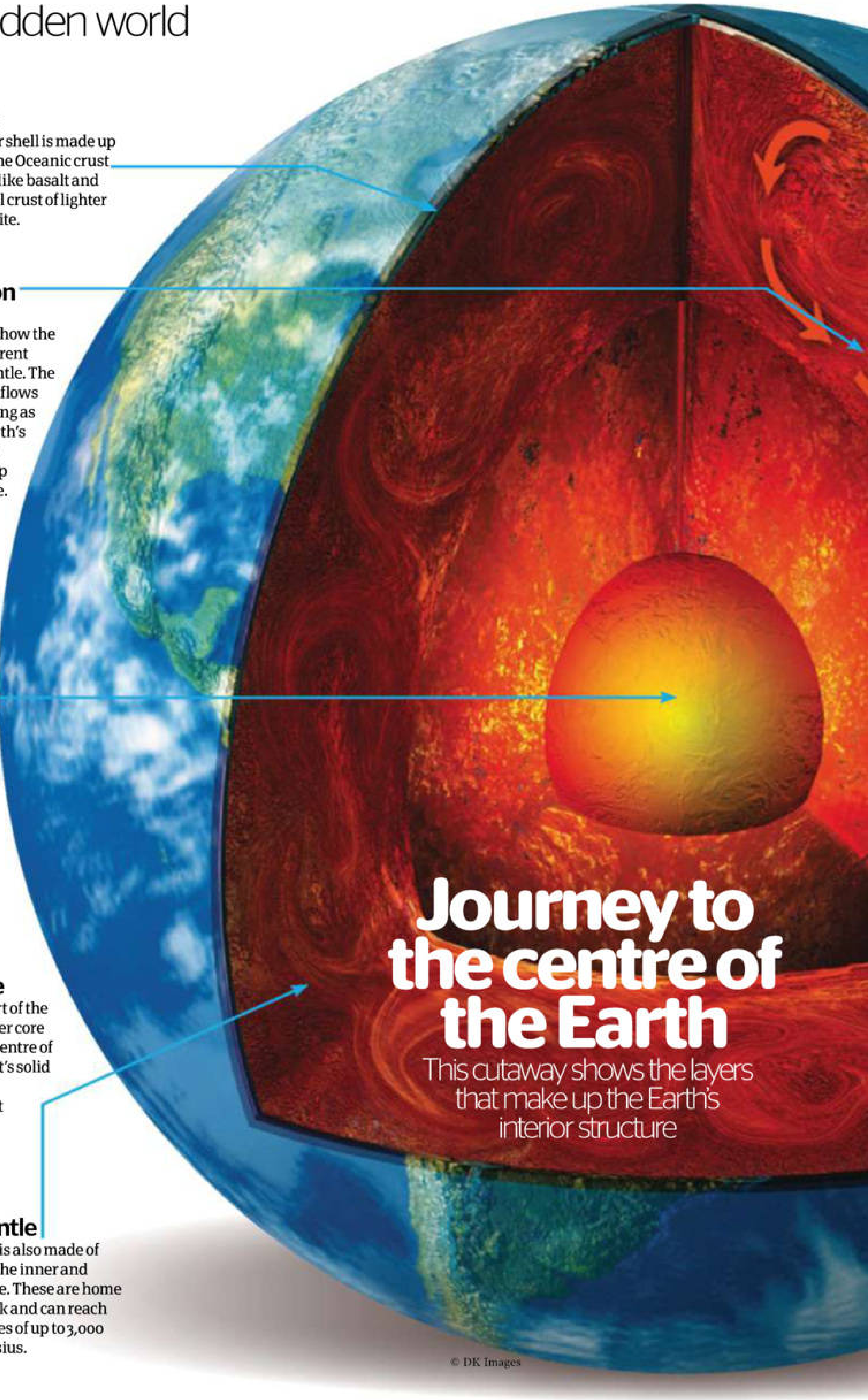
We take the world around us for granted, but the Earth that we walk upon is a complex blend of layers that together create our planet. Thanks to research in the field of seismology, we now know the makeup of the Earth, its distances and measurements and we even know enough about it to be able to compare it to other planets in our solar system.

Essentially, the internal structure of the Earth is made up of three core elements: the crust, the mantle and the core. The crust is the hard outer shell that we live on, split into Oceanic and Continental crusts, and it is comparatively thin. The first layer, the Oceanic crust, is around four to seven miles thick, made up of heavy rocks, whereas the lighter Continental crust is thicker, at approximately 19 miles.

Below the crust is the mantle, and again this is divided into two distinct layers: the inner and outer mantle. The outer mantle is the thinner of the two layers, occurring between seven miles and 190 miles below the Earth's surface. The outer mantle is made up of a bottom layer of tough liquid rock, with a temperature of somewhere between 1,400 degrees Celsius and 3,000 degrees Celsius, and a thinner, cooler upper layer. The inner mantle is deep into the Earth's structure, at between 190 and 1,800 miles deep, with an average temperature of 3,000 degrees Celsius.

Finally, we reach the Earth's core, which is 1,800 to 3,200 miles beneath our feet. The outer core is around 1,370 miles thick, encasing the inner core, which falls down to 3,960 miles below the Earth's surface. The inner core reaches a temperature high of 6,000 degrees Celsius and is made up of iron, nickel and other elements. While the outer core is liquid, the inner core is solid, and the two work together to cause the Earth's magnetism.

> "The internal structure of the Earth is made up of three core elements: the crust, the mantle and the core"



The crust
The hard, outer shell is made up of two layers: the Oceanic crust of heavy rocks like basalt and the Continental crust of lighter rocks like granite.

Convection currents
These arrows show the convection current within the mantle. The current of heat flows upwards, cooling as it nears the Earth's surface, which causes it to drop back to the core.

Inner core
The hottest part of the planet, the inner core is literally the centre of the Earth and it's solid due to its heat, meaning that it doesn't move.

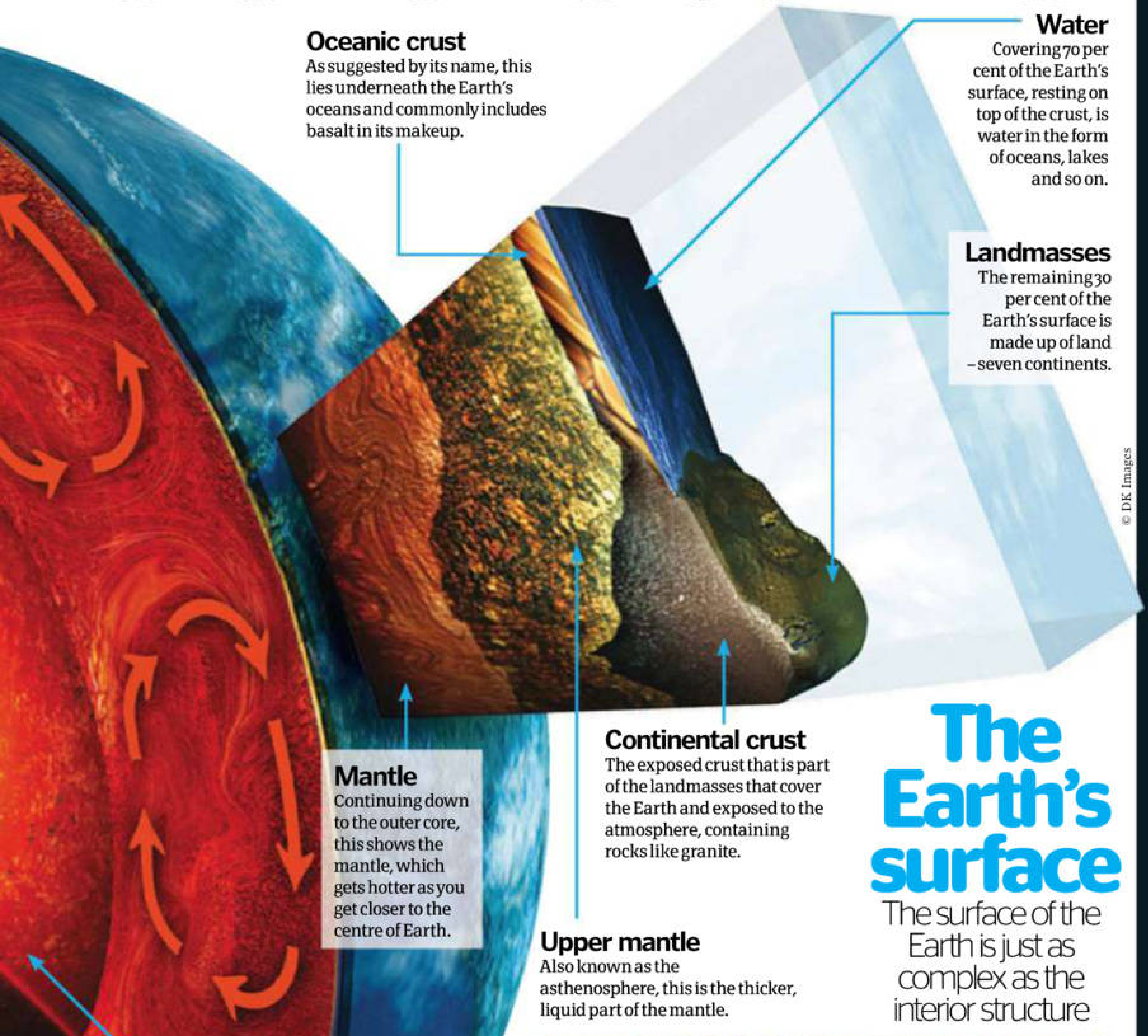
The mantle
The mantle is also made of two layers: the inner and outer mantle. These are home to liquid rock and can reach temperatures of up to 3,000 degrees Celsius.

Journey to the centre of the Earth

This cutaway shows the layers that make up the Earth's interior structure

© DK Images

structure



Oceanic crust
As suggested by its name, this lies underneath the Earth's oceans and commonly includes basalt in its makeup.

Water
Covering 70 per cent of the Earth's surface, resting on top of the crust, is water in the form of oceans, lakes and so on.

Landmasses
The remaining 30 per cent of the Earth's surface is made up of land – seven continents.

Mantle
Continuing down to the outer core, this shows the mantle, which gets hotter as you get closer to the centre of Earth.

Continental crust
The exposed crust that is part of the landmasses that cover the Earth and exposed to the atmosphere, containing rocks like granite.

Upper mantle
Also known as the asthenosphere, this is the thicker, liquid part of the mantle.

Outer core
The liquid, outer core is made up of iron, nickel, sulphur and oxygen. This outer core spins as the Earth rotates.

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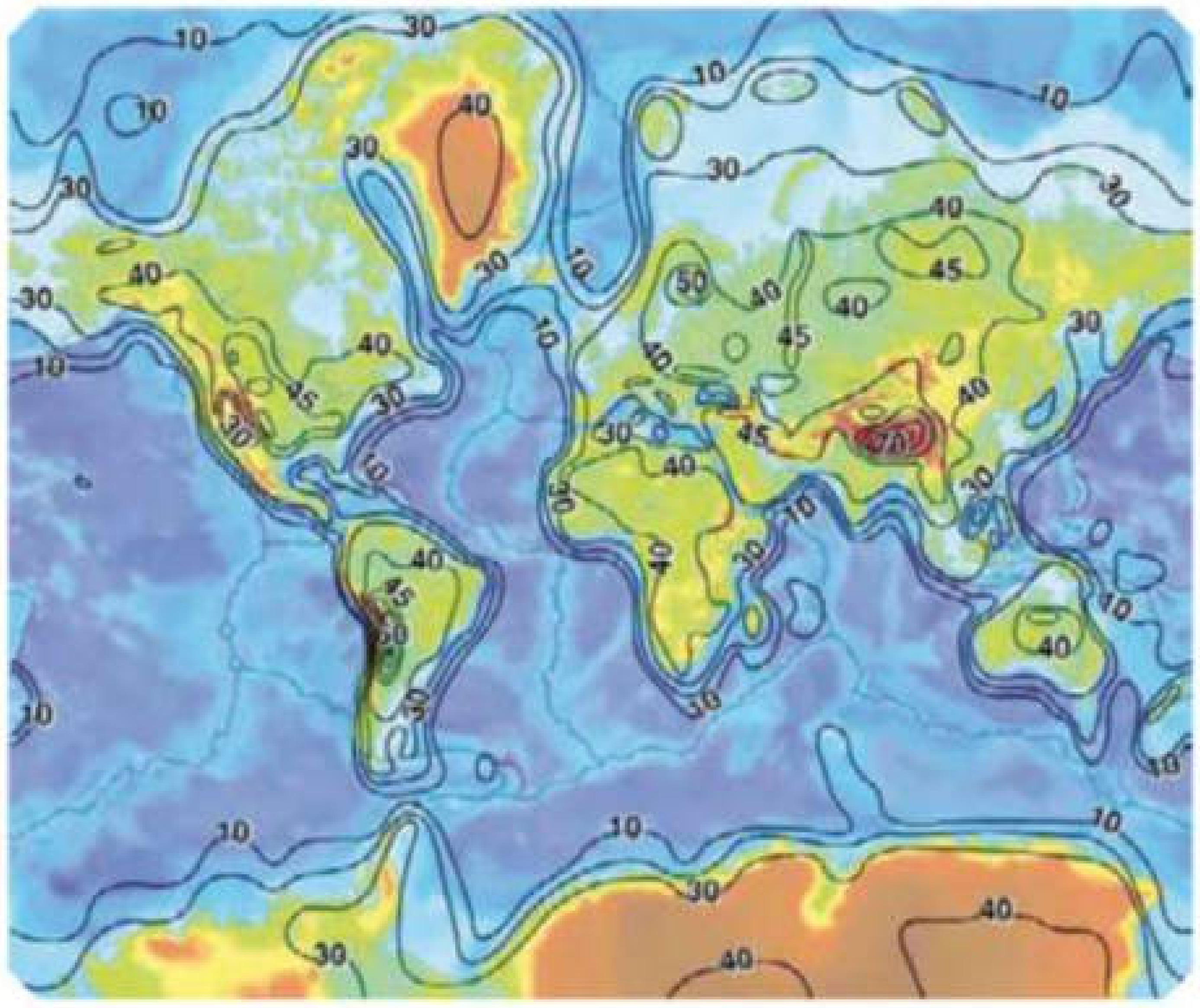
The Earth's surface

The surface of the Earth is just as complex as the interior structure



Crust thickness

A contour map of the globe, showing the thickness of the Earth's crust, with the numbers in kilometres.

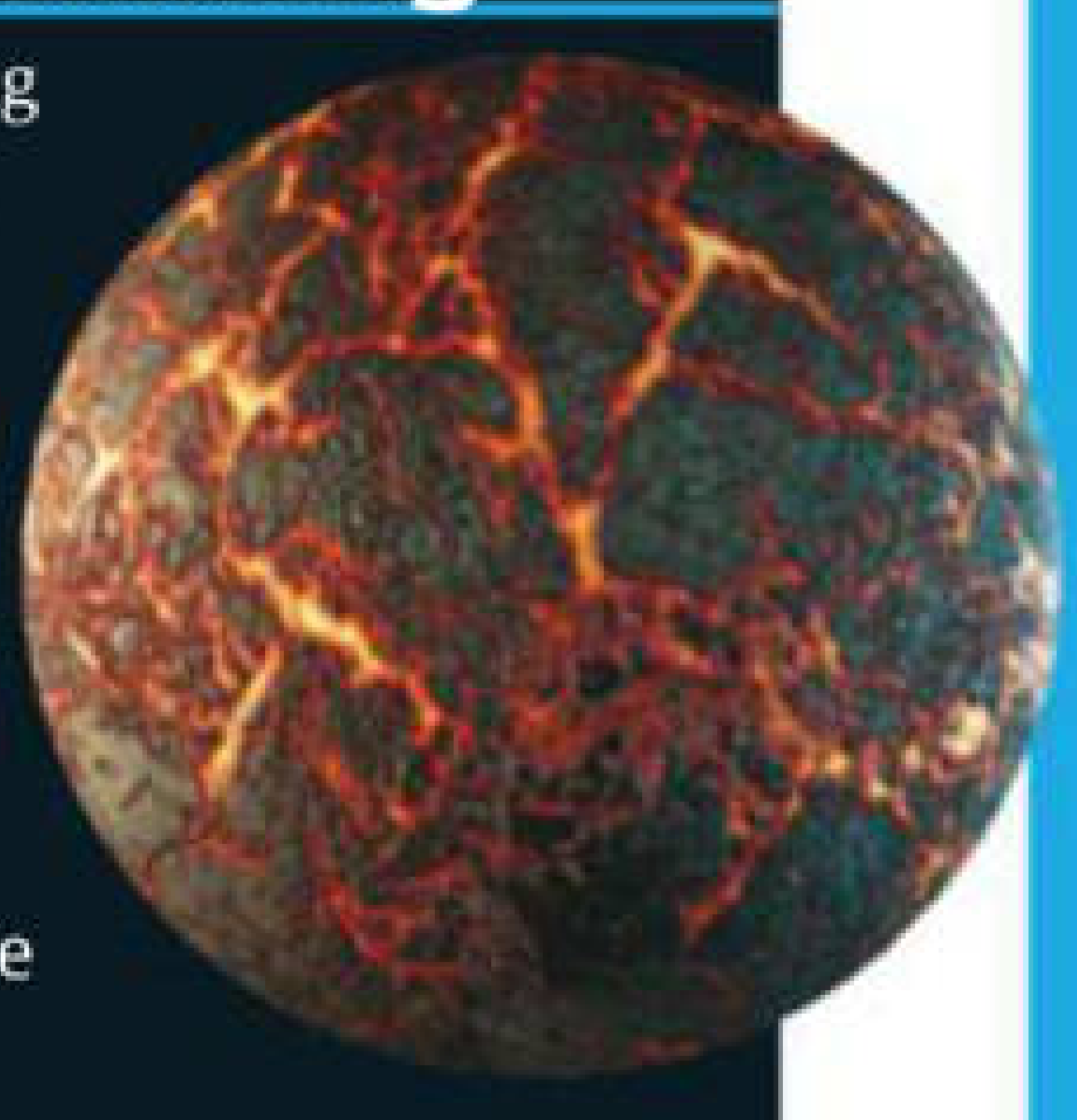
How the Earth formed

A complicated procedure brought together the many elements of the Earth and even today the planet is adapting and changing

Accretion

Accretion describes the gradual increase in size of an object through the piecemeal accumulation of additional layers. In the case of Earth, this is how rocks and metals built upon each other to form the core.

Heating and cooling

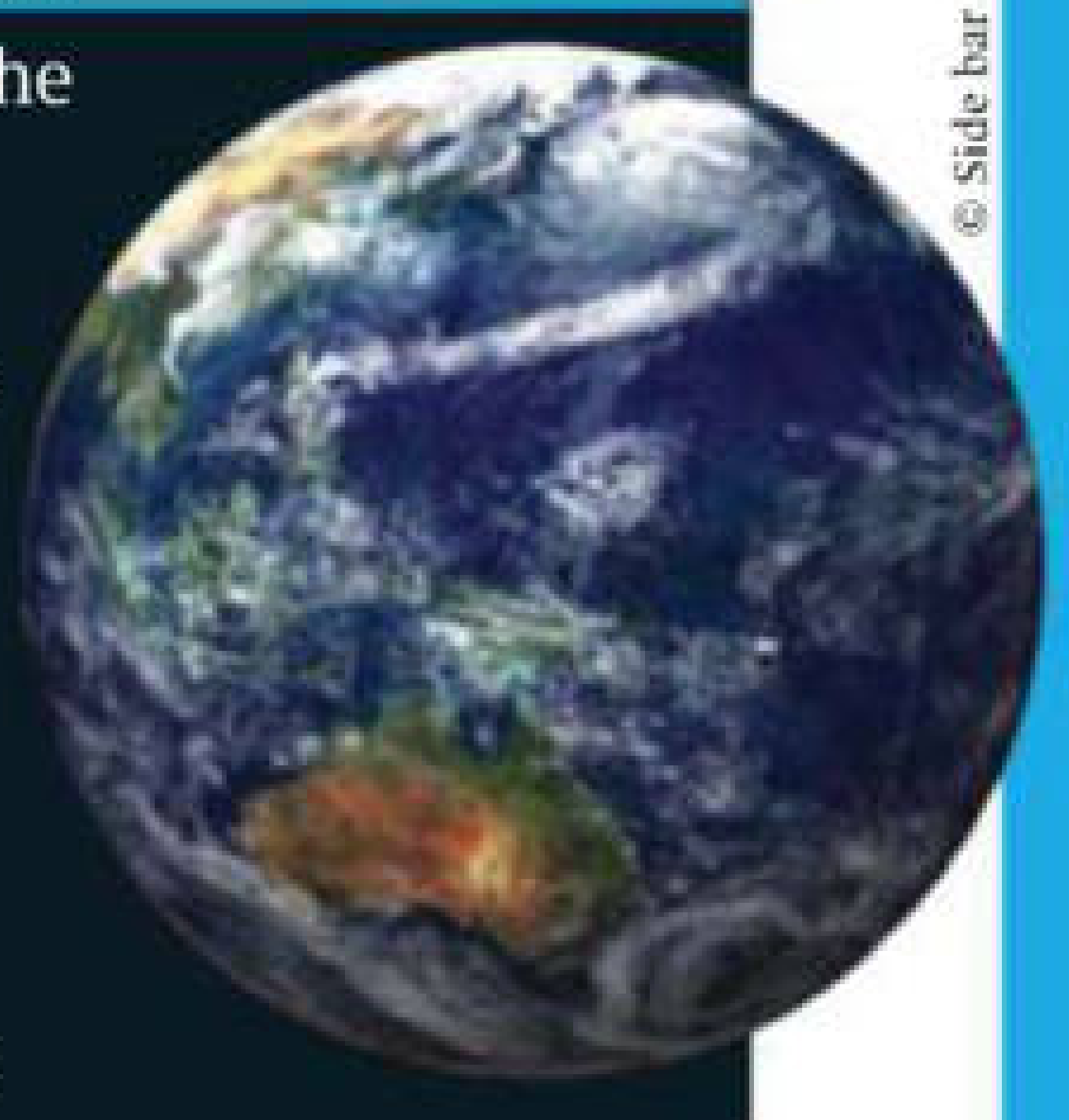


The process of creating planets via accretion causes friction and collisions that create a heat, which partly explains the temperature at the Earth's core. As this cooled during the planet's formation, the crust hardened.

Oceans and atmosphere

Steam from the crust combined with gases ejected from volcanoes to create the atmosphere and water. As the planet cooled, clouds formed, causing rain, which in turn caused the oceans.

Today's Earth



Though we rarely see the results, the Earth's surface continues to change as landmasses collide and break apart, thanks to the dynamic properties of the Earth's interior structure, which can move landmasses by centimetres each year.

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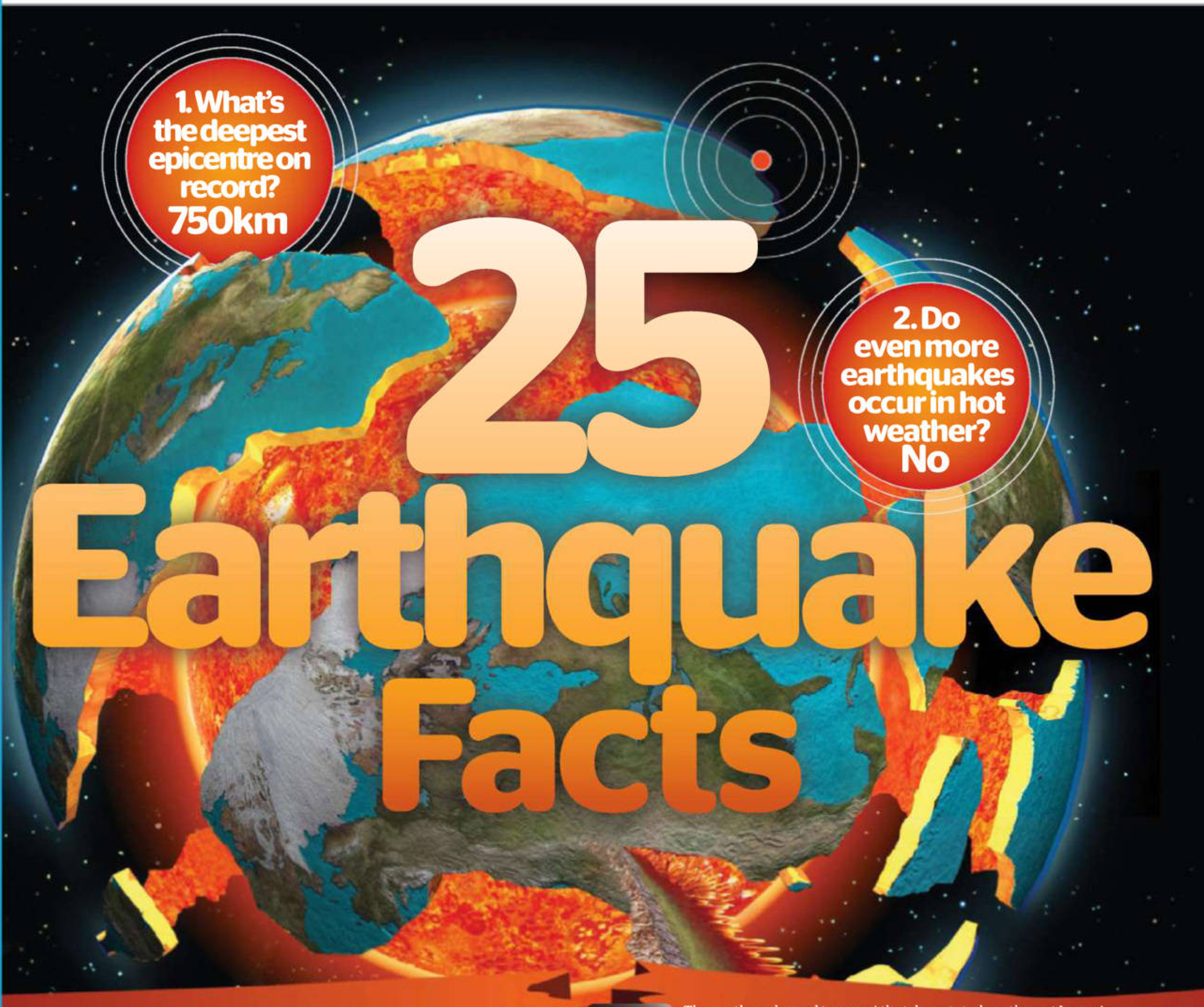


25 Earthquake Facts

1. What's the deepest epicentre on record?
750km

2. Do even more earthquakes occur in hot weather?
No

Can earthquakes make days shorter? Are there quakes elsewhere in space? Find out now…

The earthquake and tsunami that devastated north-east Japan in March 2011 demonstrate the terrifying power of these natural phenomena. Almost 16,000 people died and more than a million buildings either wholly or partly collapsed.

A year after the event, 330,000 people were still living in hotels or in other temporary accommodation, unable to return home. A further 3,000 people were still listed as missing. The gigantic tsunami waves spawned by the earthquake inundated the power supply and cooling of three reactors at the Fukushima Daiichi power station. The subsequent nuclear accident – the worst to occurr since Chernobyl – caused worldwide panic.

Earthquakes are unstoppable and strike with little or no warning, but we know a growing amount about how they work. Scientists have developed networks of sensors for monitoring ground movements, changes in groundwater and magnetic fields, which may indicate an impending quake. Engineers, meanwhile, have created new forms of architecture to resist earthquakes when they do strike. So without further ado, let's learn some earth-shattering facts…

3. What is Earth's crust made of?

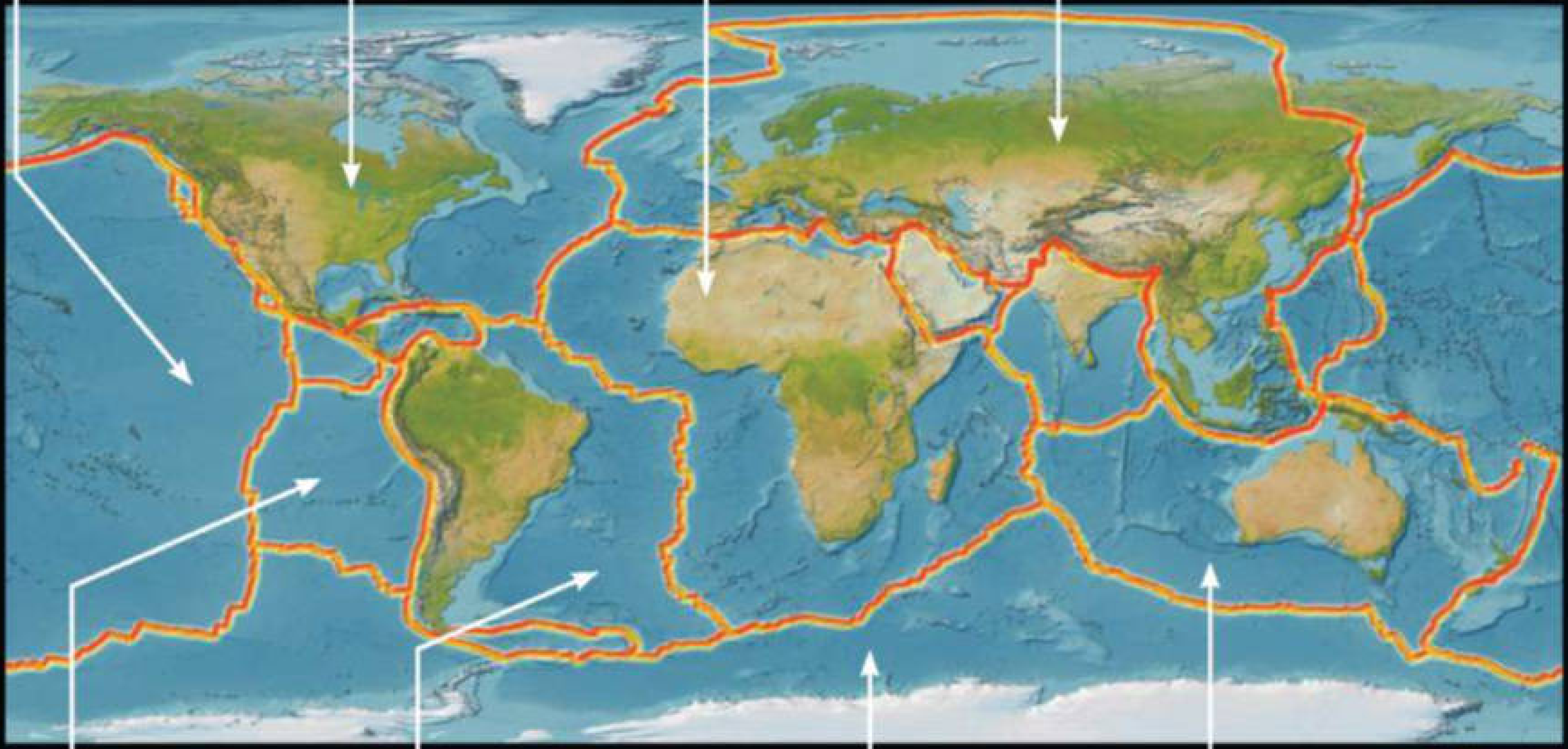
The crust consists of rock that is broken up into several moving slabs, called plates. These plates float on the denser rocks of the mantle, a sticky layer lying between the planet's core and the crust. Granite is the most common rock in the crust that makes up Earth's continents. This continental crust is on average 35 kilometres (22 miles) thick, deepest beneath mountain ranges. Ocean floor crust is thinner – on average 6 kilometres (4 miles) – and mainly made of denser volcanic rocks, such as basalt. Granite is 75 per cent oxygen and silicon. Basalt is denser as the silicon is contaminated with heavier elements like iron.

Pacific Plate
Earth's biggest plate is among the fastest moving, travelling north-west some 7 cm (3 in) annually.

North American Plate
The continent of North America and some of the Atlantic Ocean floor sit on this plate.

African Plate
This plate carrying the African continent carries some of the world's most ancient crust – up to 3.6 billion years old.

Eurasian Plate
The Himalayas, Earth's highest mountain range, is rising as the Indian Plate thrusts beneath the Eurasian Plate.



Nazca Plate
The Nazca Plate located off South America's west coast is one of several smaller plates.

South American Plate
South America's collision with the Nazca Plate is lifting up the Andes, our planet's longest mountain range.

Antarctic Plate
Until 45 million years ago, the Antarctic Plate was joined to the Australian Plate.

Indo-Australian Plate
The Indo-Australian Plate may be splitting apart to form separate Indian and Australian Plates.

4. Did the 2011 quake in Japan shorten the days on Earth?

Yes, but you're unlikely to notice. Every day is now 1.8 microseconds shorter, according to NASA. The Japan quake made Earth spin a bit faster by changing its rotation around an imaginary line called the figure axis. The Earth's mass is balanced around the figure axis, and it wobbles as it spins. That wobble naturally changes one metre (3.3 feet) a year due to moving glaciers and ocean currents. The 2011 Tohoku quake moved the ocean floor near Japan as much as 16 metres (53 feet) vertically and 50 metres (164 feet) horizontally – the equivalent horizontal distance to an Olympic swimming pool! The shifting seabed increased Earth's wobble around the figure axis by 17 centimetres (6.7 inches). As the wobble grew, Earth's rotation sped up. It's the same principle as when a figure skater pulls their arms closer to their body to spin faster.

5. What is the shadow zone of an earthquake?

A shadow zone is the location on the Earth's surface at an angle of 104-140 degrees from a quake's origin that doesn't receive any S-waves or direct P-waves. S and P-waves are seismic waves that can travel through the ground; basically, shockwaves created when a fault suddenly moves. Shadow zones occur as S-waves can't pass through the Earth's liquid outer core, while P-waves are refracted by the liquid core.

6. Where is the quake capital?

Around 90 per cent of earthquakes occur on the so-called Ring of Fire, a belt of seismic activity surrounding the Pacific Plate. The Ring of Fire is a massive subduction zone where the Pacific Plate collides with and slides beneath several other plates. Most quakes are measured in Japan, as it lies on the Ring of Fire at the junction of the Pacific, Philippine, Eurasian and Okhotsk Plates. Japan has a dense earthquake-monitoring network, so scientists can detect even small quakes. The volcanic island chain of Indonesia probably experiences the most earthquakes based on landmass, yet it has fewer instruments for measuring them.

7. Are earthquakes more likely to occur in the morning?

No

8 What are tremors?

A tremor is simply another word for an earthquake. It's also another word for the vibrations that you experience whenever an earthquake hits. The earth itself trembles because movement energy is released during an earthquake, which causes the ground to vibrate in all directions.

9 How can scientists tell how far away an earthquake occurred?

Scientists use a seismometer to record earthquake waves called P and S-waves (ie Primary and Secondary waves). P-waves travel faster than S-waves and can pass also through liquids, such as the outer core and mantle. By measuring the delay between the P and S-waves arriving, they can calculate the distance the waves travelled.

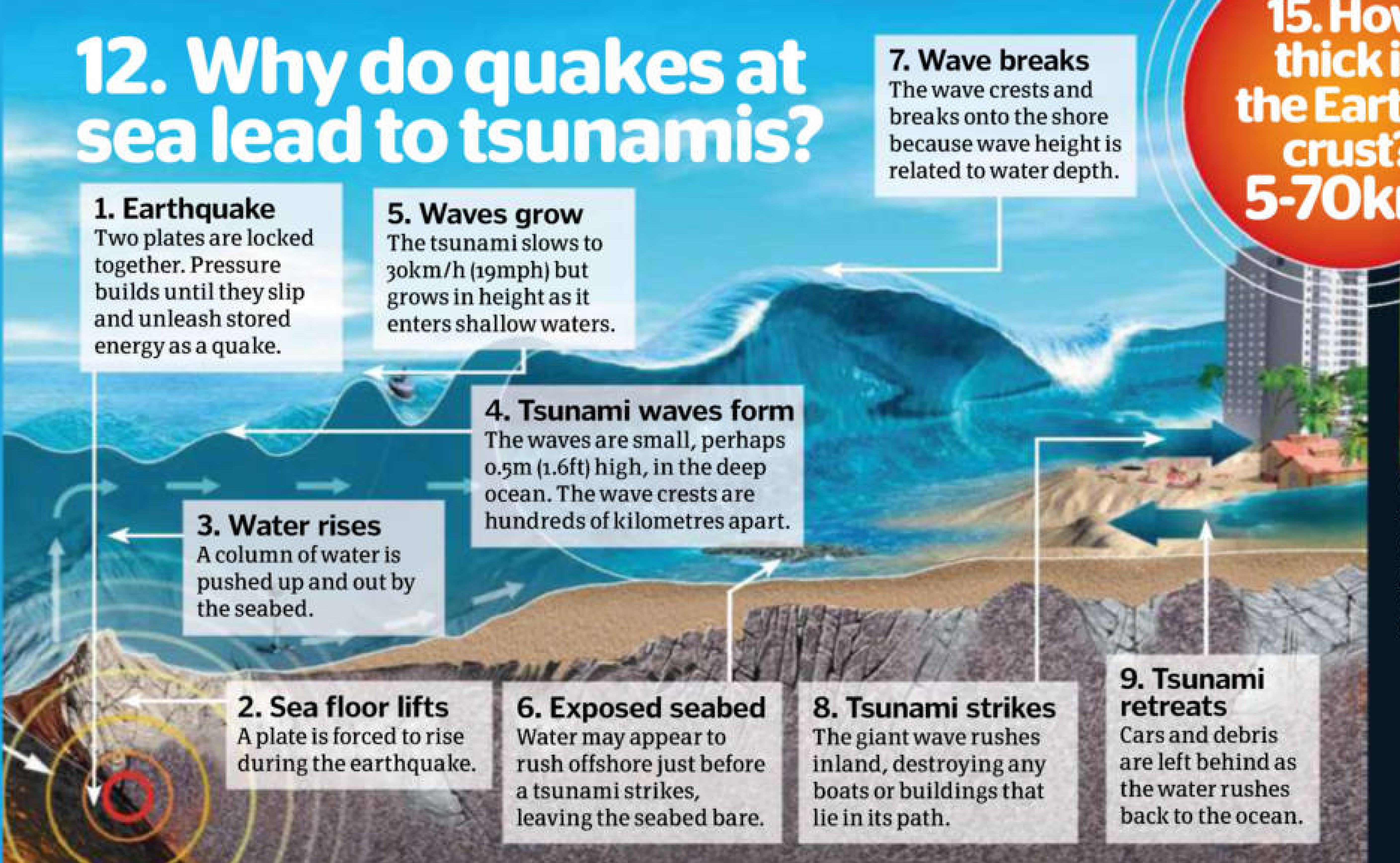
10 What's the earliest recorded major earthquake in history?

The first earthquake ever described was in China in 1177 BCE. By the 17th century, descriptions of the effects of earthquakes were published worldwide, although of course these accounts were often exaggerated and less detailed than data recorded today.

11 What do the lines on a seismometer reading represent?

The wiggly lines on a seismogram represent the waves recorded. The first big wiggles are P-waves. The second set of wiggles are S-waves. If the latter are absent, the quake happened on the other side of the planet.

12. Why do quakes at sea lead to tsunamis?



1. Earthquake
Two plates are locked together. Pressure builds until they slip and unleash stored energy as a quake.

2. Sea floor lifts
A plate is forced to rise during the earthquake.

3. Water rises
A column of water is pushed up and out by the seabed.

4. Tsunami waves form
The waves are small, perhaps 0.5m (1.6ft) high, in the deep ocean. The wave crests are hundreds of kilometres apart.

5. Waves grow
The tsunami slows to 30km/h (19mph) but grows in height as it enters shallow waters.

6. Exposed seabed
Water may appear to rush offshore just before a tsunami strikes, leaving the seabed bare.

7. Wave breaks
The wave crests and breaks onto the shore because wave height is related to water depth.

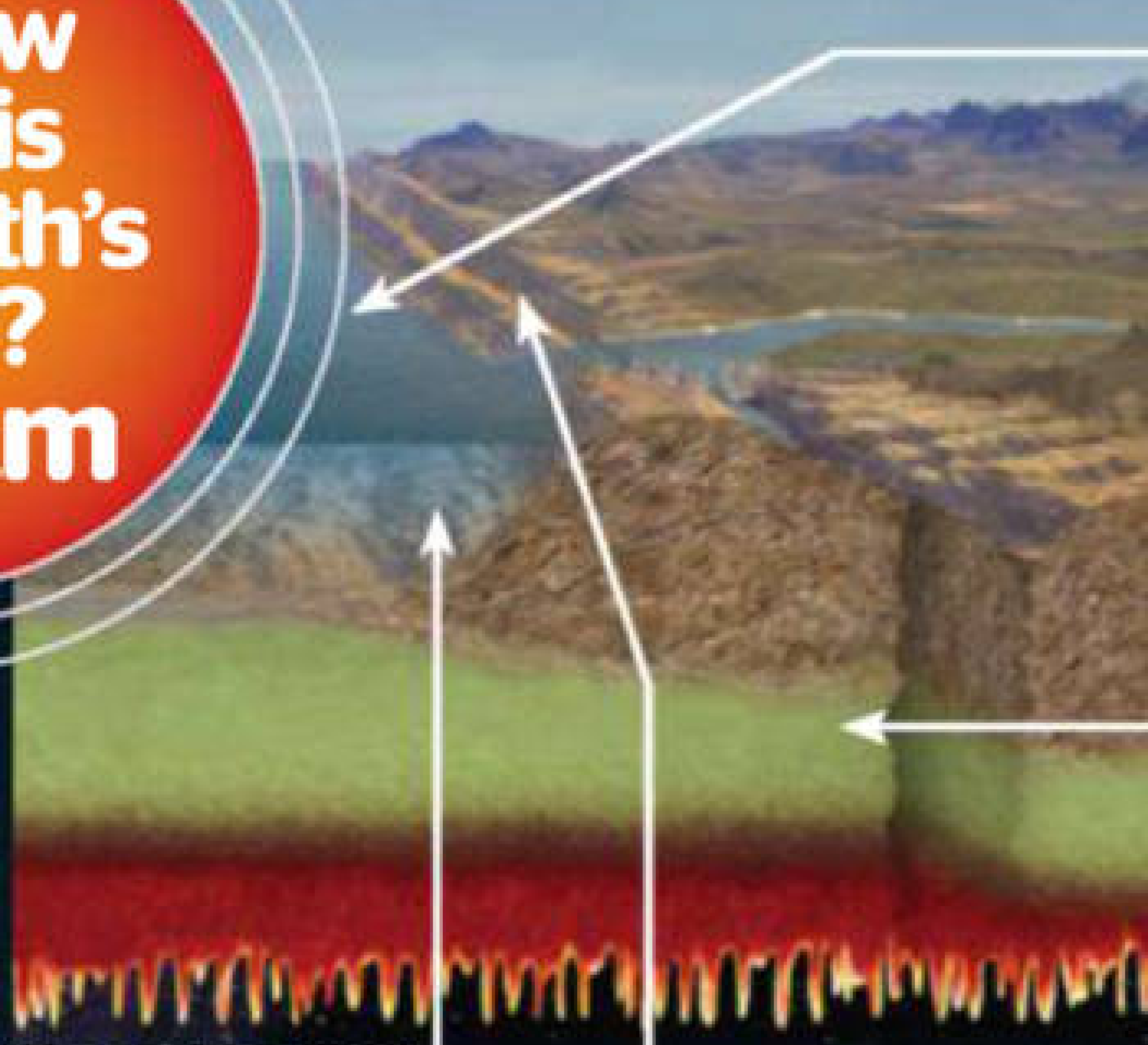
8. Tsunami strikes
The giant wave rushes inland, destroying any boats or buildings that lie in its path.

9. Tsunami retreats
Cars and debris are left behind as the water rushes back to the ocean.

Earthquakes trigger tsunamis by generating ripples in the ocean, similar to the effect of sloshing water in a glass. Tsunamis are essentially gigantic waves, which can cross oceans at speeds similar to jet aircraft, up to 700 kilometres (435 miles) per hour, and they often reach heights of 20 metres (66 feet) as they hit the coast, though far taller waves have been recorded – 524 metres (1740 feet) at Lituya Bay, Alaska, in 1958 is the highest. They sweep inland faster than running speed, carrying away people and buildings alike. The 2004 Indian Ocean tsunami, for example, claimed 300,000 lives and made nearly 2 million more homeless.

15. How thick is the Earth's crust?

5-70km



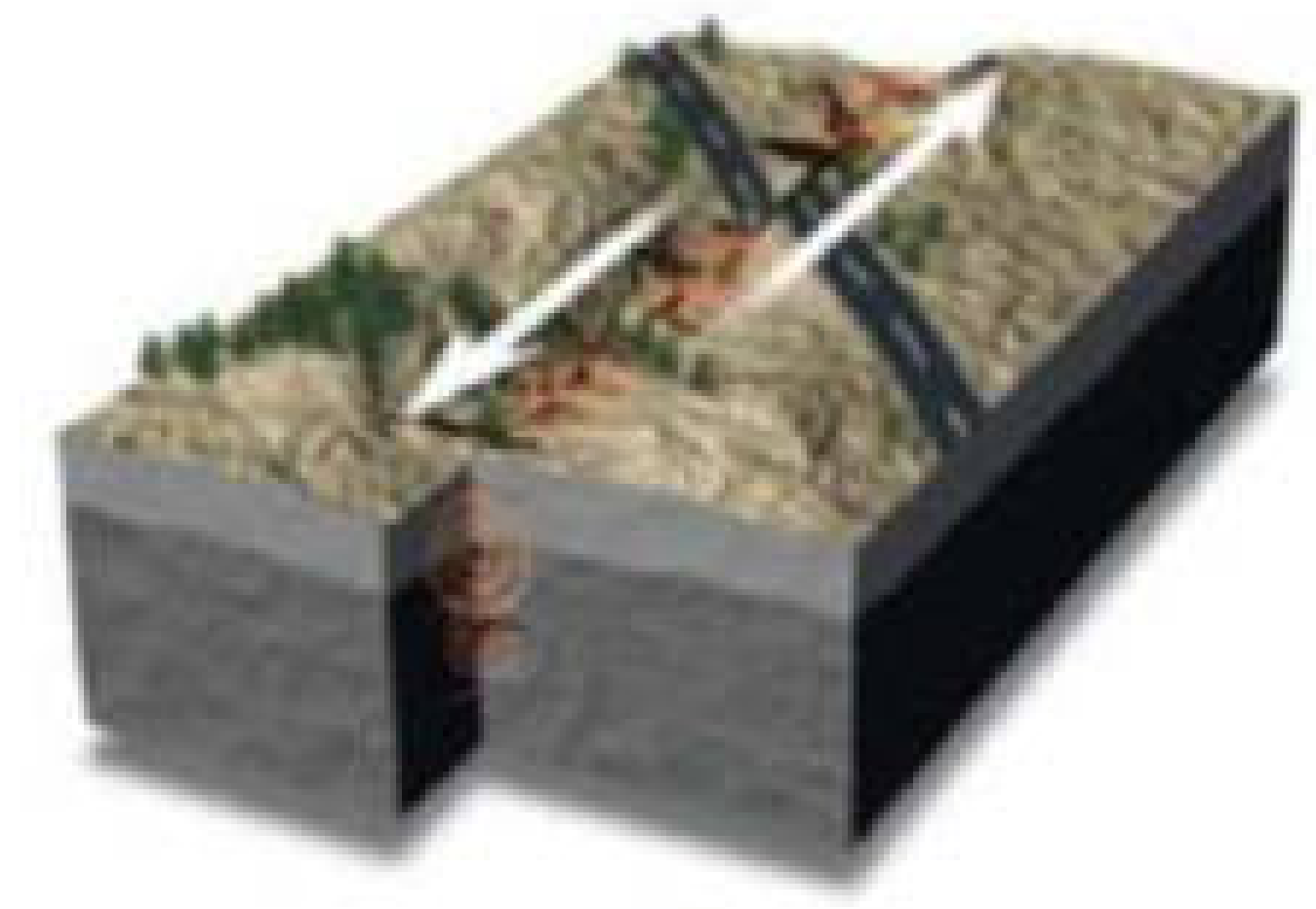
Oceanic crust
The Pacific Plate is mainly oceanic crust, which is younger and thinner than continental crust – about 5-10km (3-6mi) thick.

San Andreas Fault
The San Andreas is a strike-slip fault created by the Pacific and North American Plates sliding by each other.

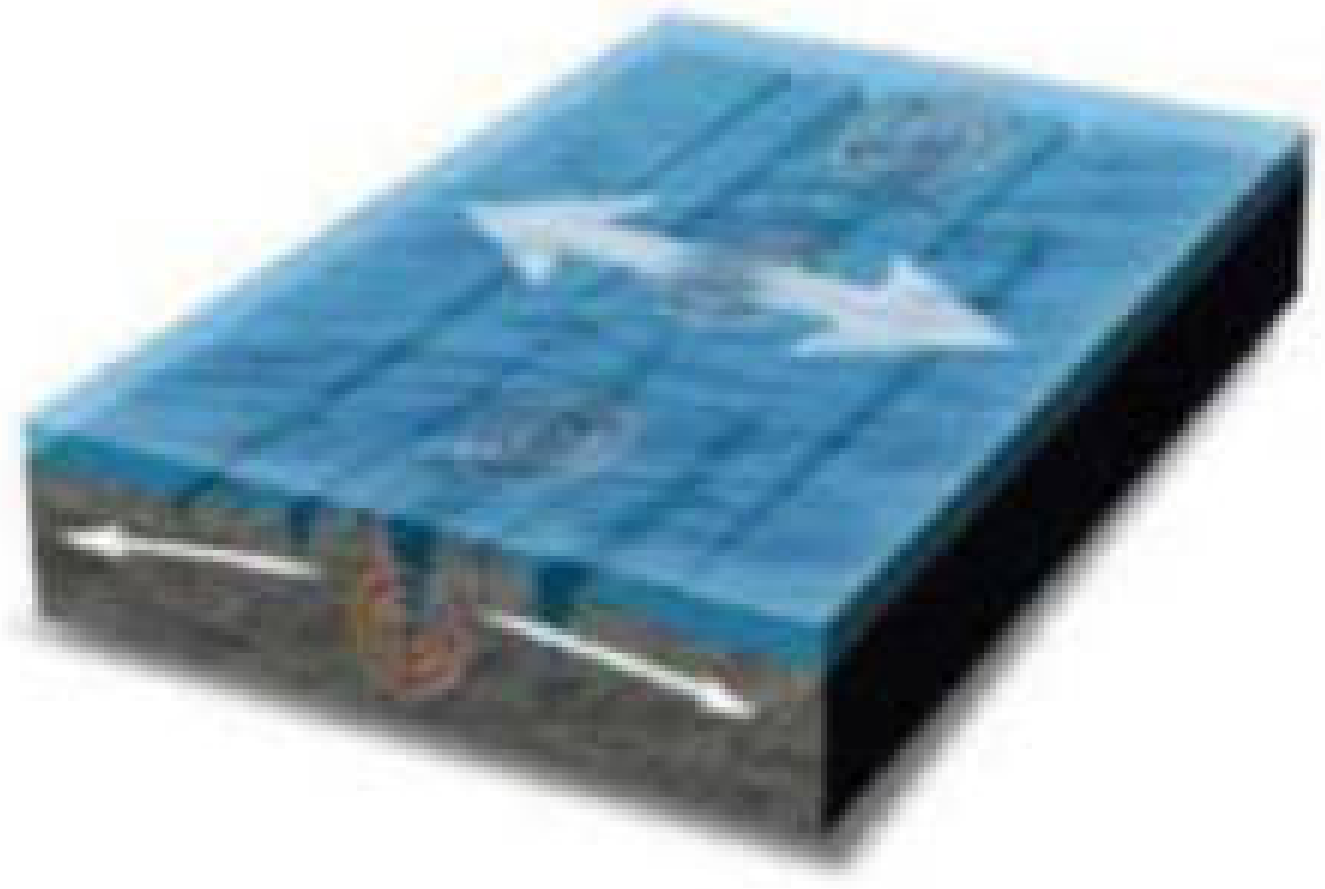
16. How many quakes occur each year?

500,000

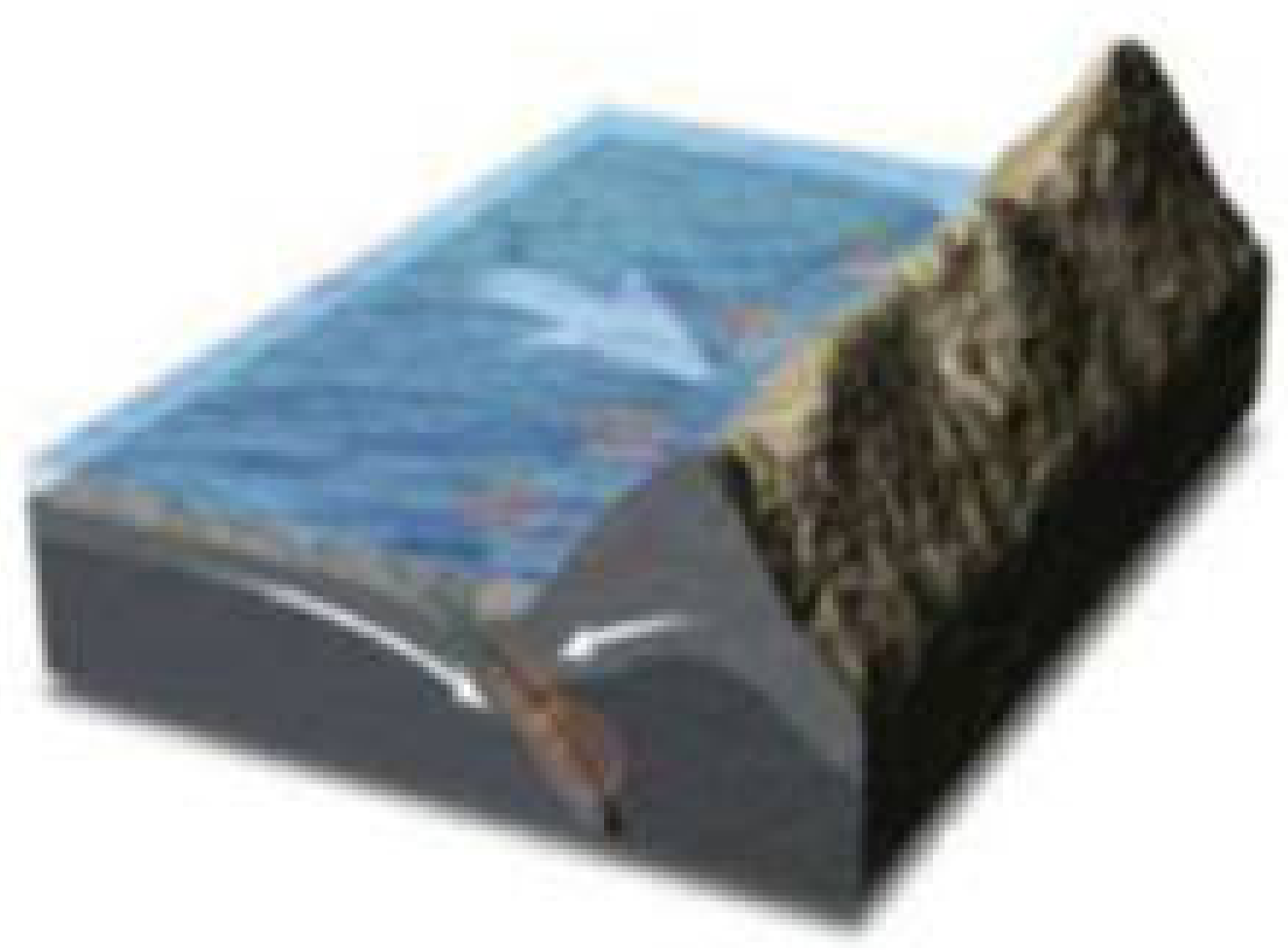
13. Are there different types of earthquake?



Strike-slip fault
Roads can be sheared apart along strike-slip faults. They're straight cracks in the crust where two plates are sliding horizontally past each other. Every time a section of the fault moves, an earthquake occurs.



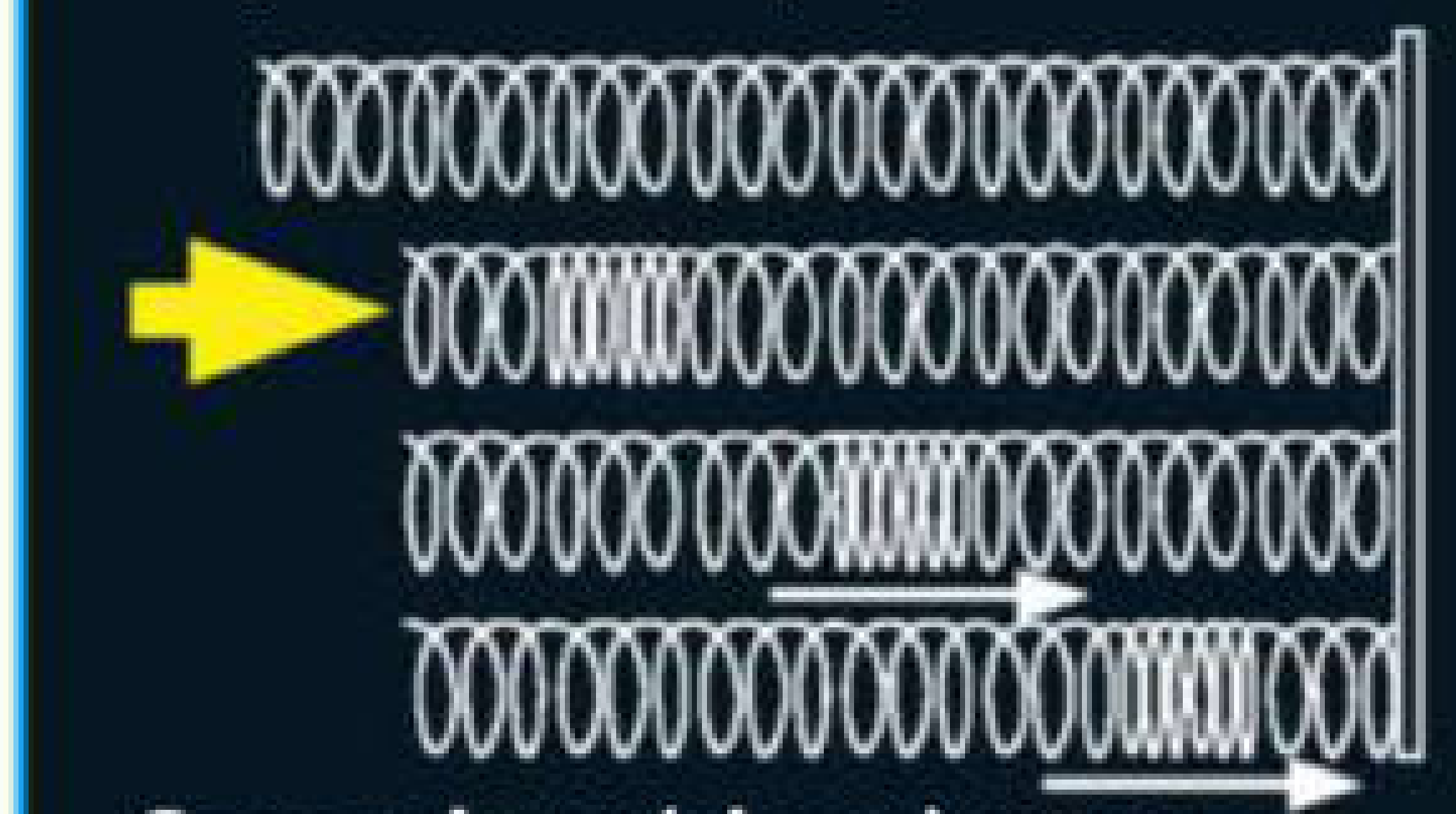
Normal fault
Earth's brittle crust becomes fractured along fault lines. Quakes occur along a normal fault when the two sides move apart. Rock slabs sitting above the fault slide down in the direction the plates are moving, like at the Mid-Atlantic Ridge.



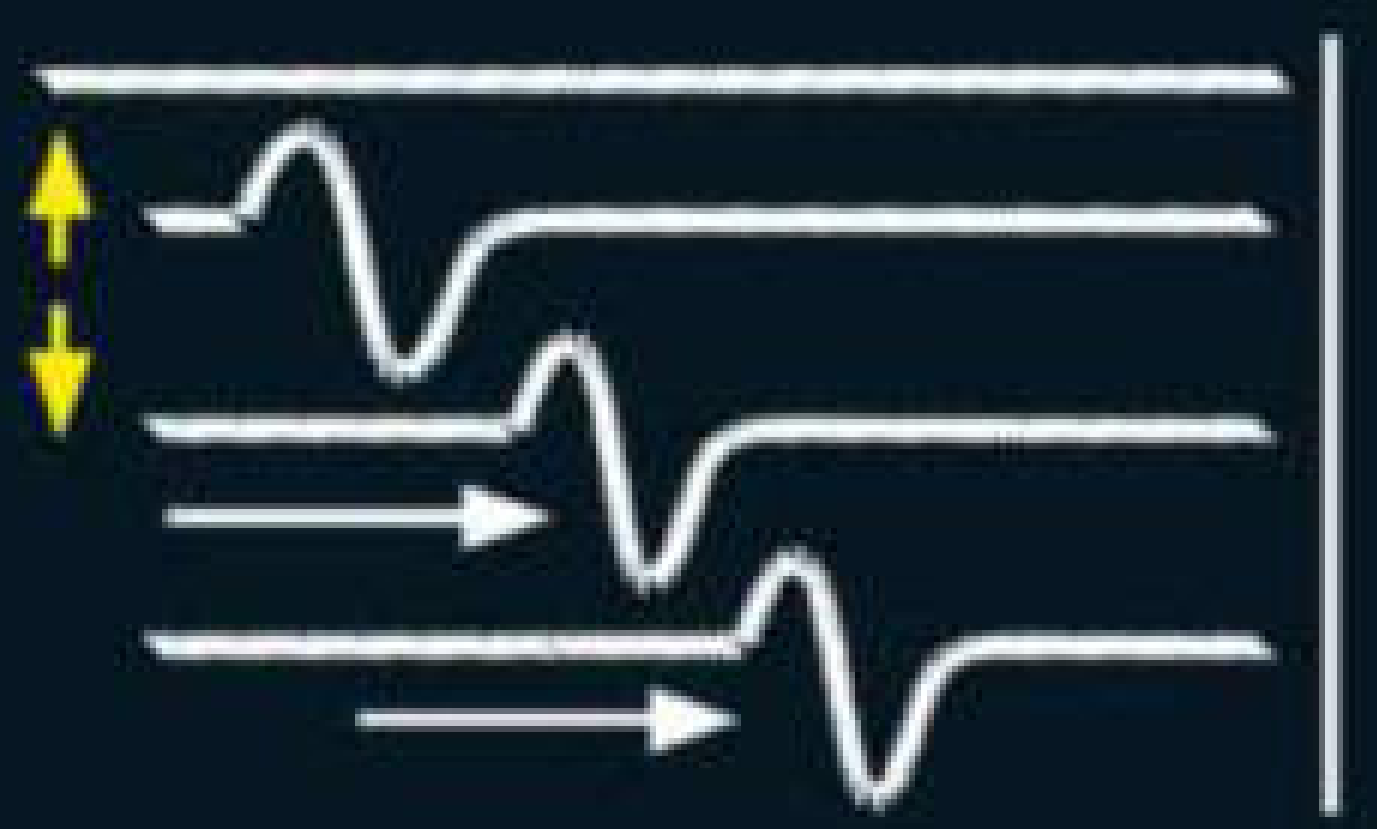
Thrust fault
2011's Tohoku quake ruptured a thrust fault in a subduction zone. Such zones are associated with the most violent quakes, as oceanic crust grinds beneath continental crust and creates great friction. Huge stresses can build here, releasing the energy of 1000 hydrogen bombs.

14. How do P and S-waves move?

Primary (compressional) waves
P-waves are the fastest waves created by an earthquake. They traverse the Earth's interior, passing through both solid and molten rock. They shake the ground back and forth – like a Slinky – in their travel direction, but do little damage as they only move buildings up and down.

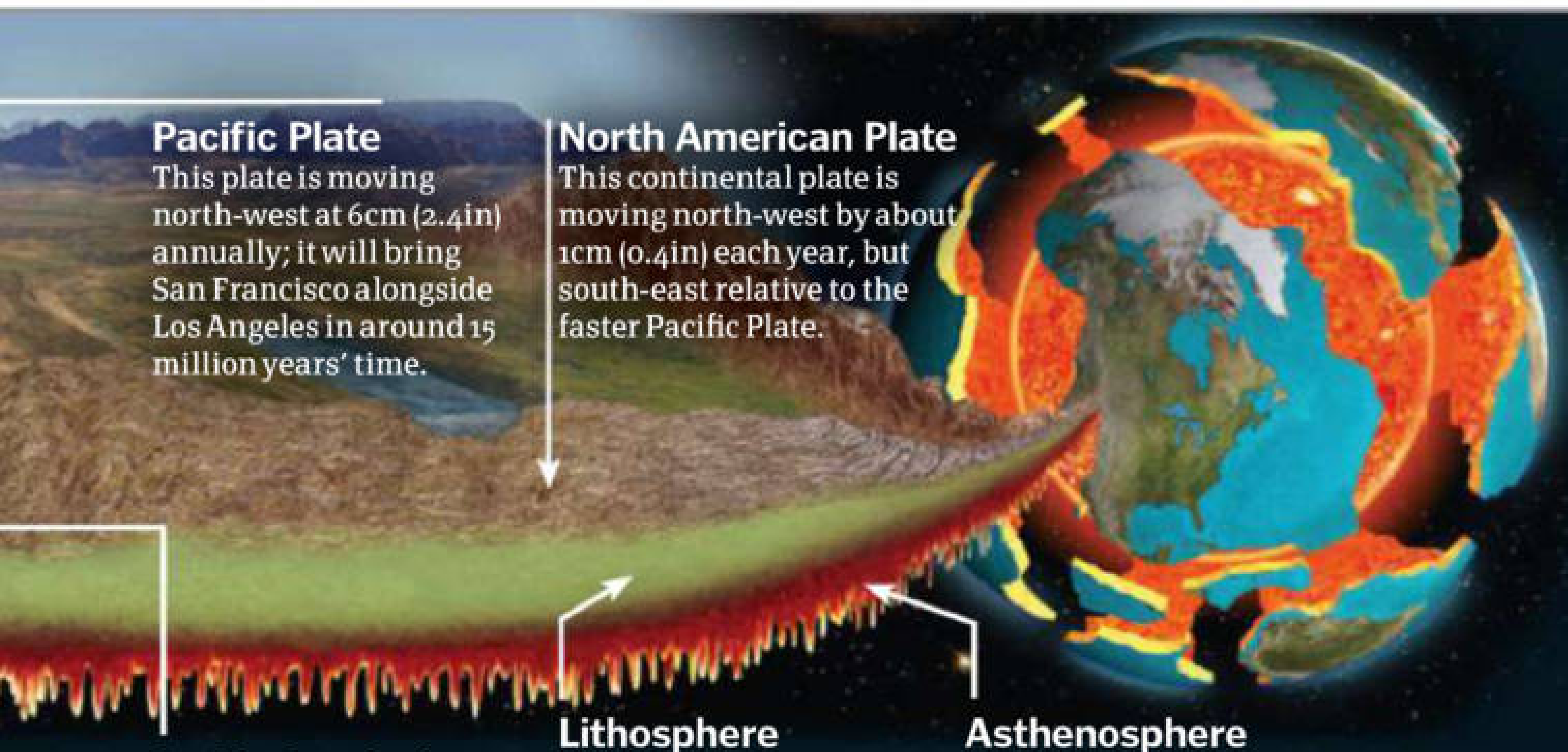


Secondary (shear) waves
S-waves lag behind P-waves, travelling 1.7 times slower and only through solid rock. However, they do more damage since they're bigger and shake the ground vertically and horizontally.



17. Do earthquakes happen off Earth?

There's evidence of 'marsquakes' on Mars as well as quakes on Venus. Titan (a moon of Saturn) and several moons of Jupiter also show signs of quakes. Seismometers on the Moon detected tidal 'moonquakes' caused by the pull of the Earth's gravity, vibrations from meteorite impacts and tremors caused by the Moon's cold crust warming after the two-week lunar night.



Pacific Plate
This plate is moving north-west at 6cm (2.4in) annually; it will bring San Francisco alongside Los Angeles in around 15 million years' time.

North American Plate
This continental plate is moving north-west by about 1cm (0.4in) each year, but south-east relative to the faster Pacific Plate.

Inside San Andreas
The fault is around 16km (10mi) deep and up to 1,600m (5,250ft) wide. Inside are small fractures and pulverised rock.

Lithosphere
The top of the mantle and crust together are known as the lithosphere, which measures about 100km (62mi) thick.

Asthenosphere
About 100-350km (62-217mi) below Earth's surface is the asthenosphere, a layer of hot, weak mantle rocks that flow slowly.

18. Why is the San Andreas Fault prone to large quakes?

Longer fault lines in the Earth's crust have larger earthquakes, which explains why the strike-slip San Andreas Fault has had several quakes that have clocked in at over magnitude 7. The San Andreas Fault extends 1,300 kilometres (800 miles) along the coast of California. When a fault ruptures, it 'unzips' along its length. Each section of the fault releases energy – the longer the fault is, the more energy there is that is released and so the bigger the associated quake with each 'unzipping' event. Scientists believe that the San Andreas Fault is currently overdue for a potential magnitude 8.1 earthquake over a 547-kilometre (340-mile) length. The southern segment has stayed static for more than a century, which has allowed enormous stresses to build up inside it.

19. Could Africa ever be split from Europe by an earthquake?

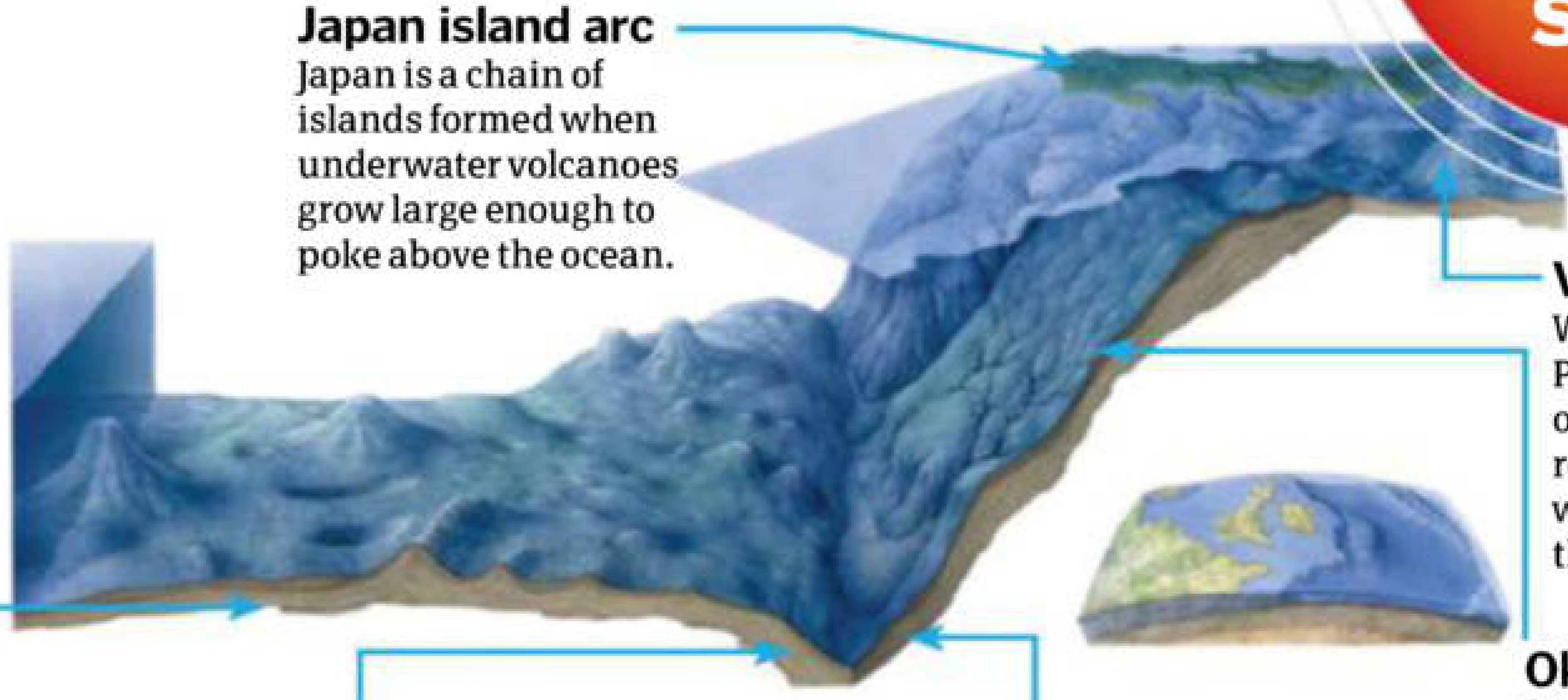
The Eurasian and African Plates are not splitting apart; they're actually moving towards each other at about 1 centimetre (0.4 inches) per year. In the future, it's possible that the Eurasian Plate may begin to slide under the African Plate. Even if the plates were moving apart, you'd need a mega-quake to yank Africa away from Europe in one go. There is no known fault long enough to create a mega-quake above magnitude 10; the most powerful in history was a 9.5.

20. How many people jumping would it take to re-create the same reading as the Tohoku earthquake?

You'd need a million times Earth's population, all jumping at once, to generate the energy released by the Tohoku earthquake. This is calculated by assuming Earth's population is 10 billion and each person generates 200 joules of energy by jumping 0.3 metres (0.98 feet).

21. How did the Japan Trench form?

A 390-kilometre (242-mile) stretch of the Japan Trench is associated with Japan's 2011 Tohoku earthquake. The trench is a vast chasm in Earth's crust at the junction between the Pacific Plate and tiny Okhotsk Plate under Japan. The Pacific Plate is moving westwards and diving beneath the Okhotsk. Friction between the two plates causes them to lock together and pressure to build. Sudden slippages release the tension in a violent burst of energy.



Japan island arc
Japan is a chain of islands formed when underwater volcanoes grow large enough to poke above the ocean.

Volcano
Water from the Pacific Plate helps melt overlying mantle rocks. Volcanoes form when this explodes through the crust.

Okhotsk Plate
The Okhotsk is a continental plate that lies beneath the northern part of Japan.

Pacific Plate
The oceanic Pacific Plate hits the much smaller Okhotsk Plate as it moves west towards Japan.

Subduction zone
The Pacific Plate slides beneath the Okhotsk Plate because it is made of denser oceanic crust.

Japan Trench
The trench is one of the deepest points in the world's oceans, up to 9km (5.6mi) below sea level.

22. How long do quakes last?

10-30 secs

23 Can animals predict quakes?

There's little evidence to indicate whether or not animals are actually capable of predicting earthquakes, but many stories exist of odd behaviour. These include tales of hibernating snakes fleeing their burrows in China in 1975, a full month before the Haicheng earthquake struck.

24 Where is the safest place to be during an earthquake?

The safest place inside is underneath a sturdy table, away from light fittings and windows. The safest place outside is out in the open away from any buildings and electricity cables.

25 If I were stood on a beach during an earthquake would I sink?

Perhaps, but it's unlikely you would drown. During an earthquake, wet sand or soil can behave like quicksand – a process called liquefaction. A quake vibrates the sand, separating the grains so that they flow like a liquid. It's extremely unusual and even then people will rarely sink below their chests during liquefaction as they will float.

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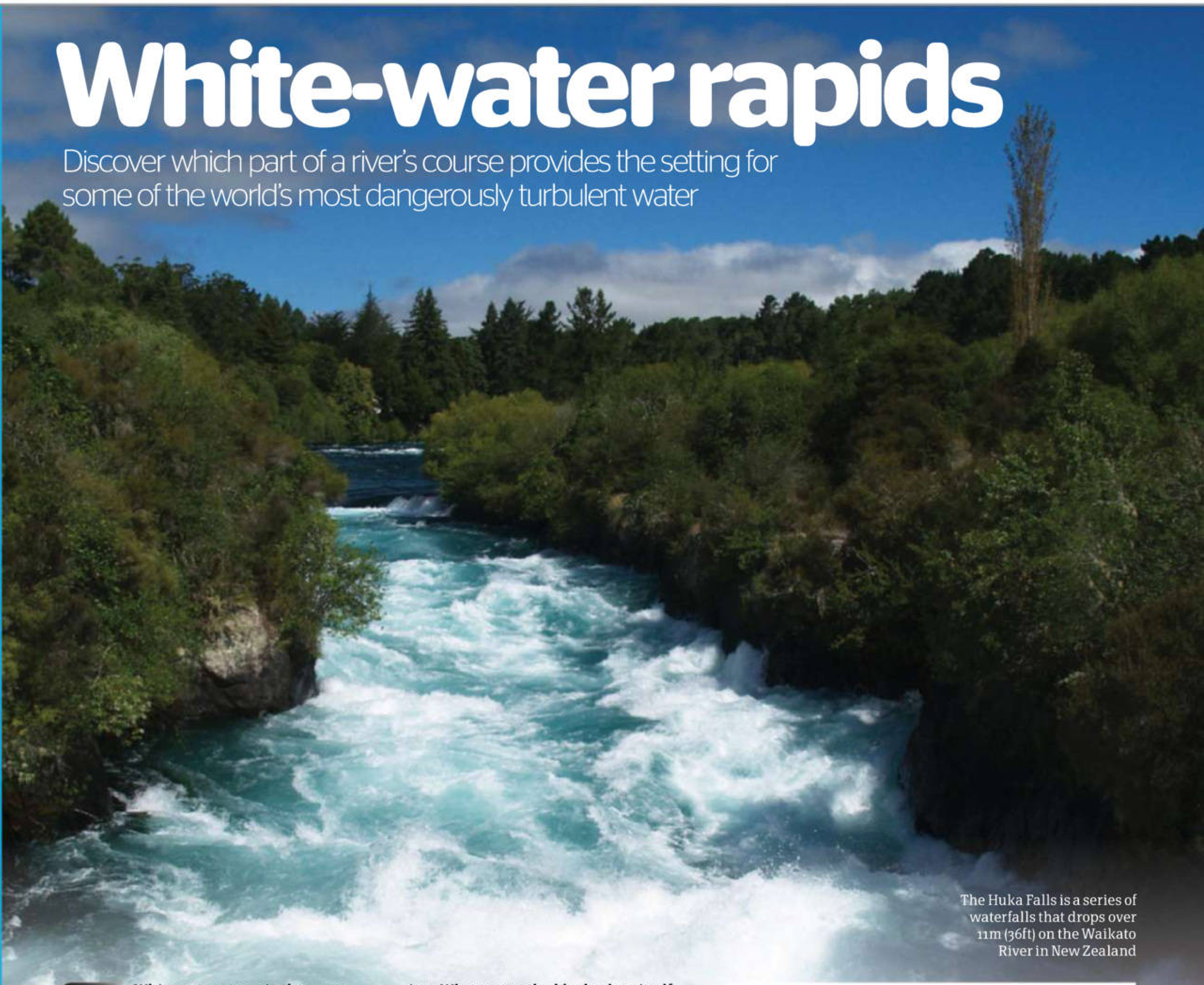
White-water rapids

Discover which part of a river's course provides the setting for some of the world's most dangerously turbulent water



The Huka Falls is a series of waterfalls that drops over 11m (36ft) on the Waikato River in New Zealand

White water occurs in the upper course of the river when the gradient and obstacles disturb the flow of water, causing it to churn and create bubbles. These bubbles reflect back much of the light that hits them, making the water appear white. Whether a river flows smoothly often depends on its speed, and the steeper the riverbed, the faster the water will flow.

The combination of fast-flowing water and obstacles like rocks causes the flow to become turbulent, with unpredictable variation in the speed and direction of the water. This creates a variety of features in the river. Where water doubles back on itself, pockets filled with bubbles open up; these provide much less buoyancy and feel like 'holes'. Objects lodged in the river, like trees, can act as strainers, allowing water to pass through, but blocking the passage of larger debris. And in areas where the water moves rapidly, it wears away at the surface of rocks underneath, creating undercuts.

The challenges of navigating the variable features of white-water rapids – whether they be jutting rocks, whirlpools or pressure waves – attract thousands of adrenaline-junkie kayakers and rafters every year.

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What causes rogue waves?

What are these freakishly giant waves that appear as if from nowhere far out at sea?

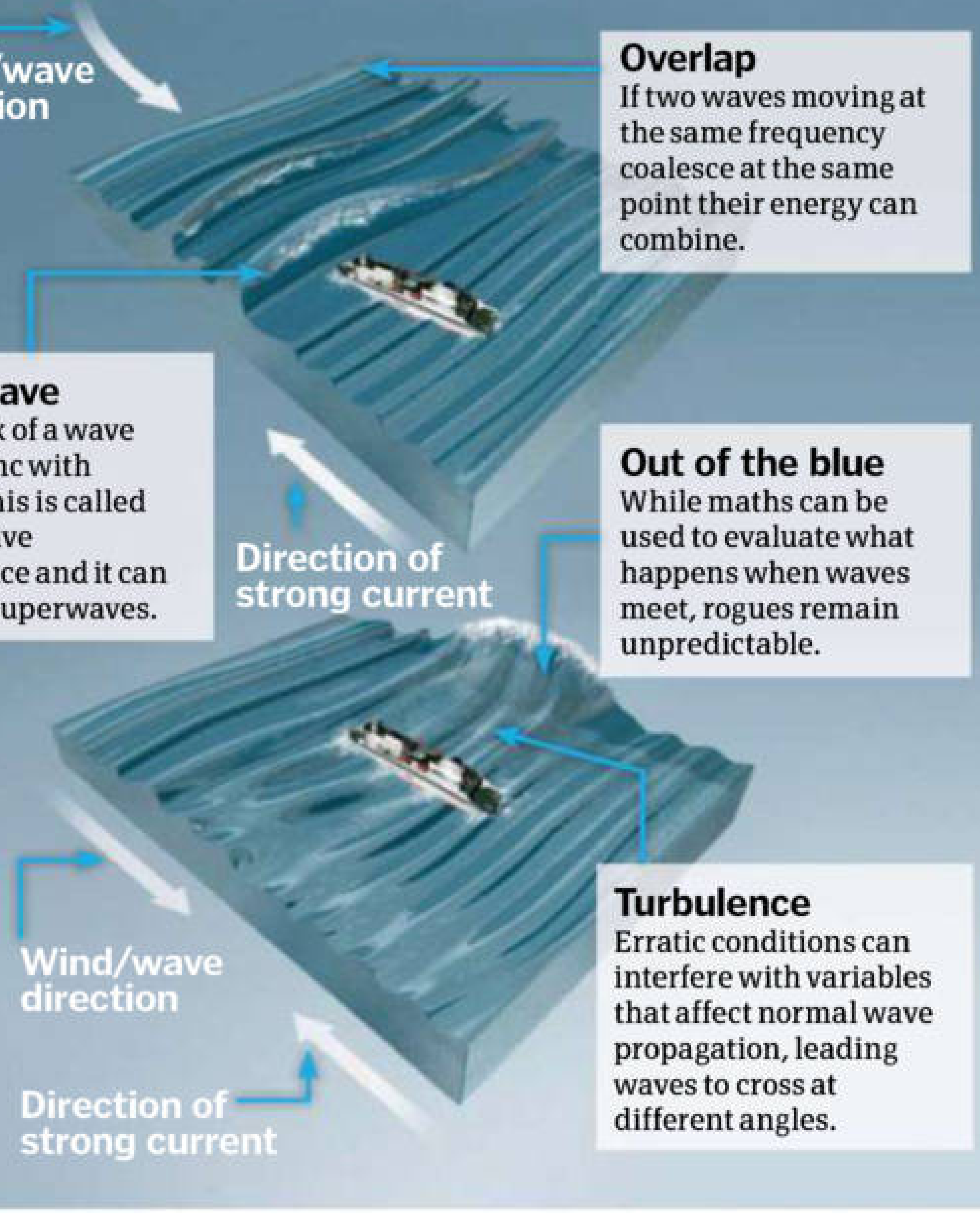
Maritime history has long told of infeasibly tall waves that strike suddenly during calm seas and topple boats. And yet to date little is understood about what causes these mystery waves. An ESA project confirmed the existence of these mammoth swells when it recorded ten waves all over 25 metres (80 feet) during a three-week period in 2001.

A rogue wave is defined as being around three times the average height of the other waves around it. So they needn't actually be massive – just surprisingly large compared with the general sea state.

Their very nature makes it difficult to predict or pinpoint their cause as factors such as water depth, currents and other variables will affect the propagation and development of a single wave.

Energy can be exchanged between multiple waves to generate abnormally large ones. For example, when a small, fast wave catches up with a large, slow wave, the energy of both can combine to create a single, high-intensity wave.

There are also specific regions of Earth more prone to rogues. The interaction of surface waves and the Agulhas Current near South Africa's east coast, for example, is thought to breed giant waves propagating from east to west. Environmental engineers at the University of Wisconsin-Madison discovered that when fast waves from one direction interact with strong currents moving in the opposite direction, a wave could rise up and 'climb' the current's wall.



Overlap
If two waves moving at the same frequency coalesce at the same point their energy can combine.

Superwave
If the peak of a wave falls in sync with another this is called constructive interference and it can generate superwaves.

Out of the blue
While maths can be used to evaluate what happens when waves meet, rogues remain unpredictable.

Turbulence
Erratic conditions can interfere with variables that affect normal wave propagation, leading waves to cross at different angles.

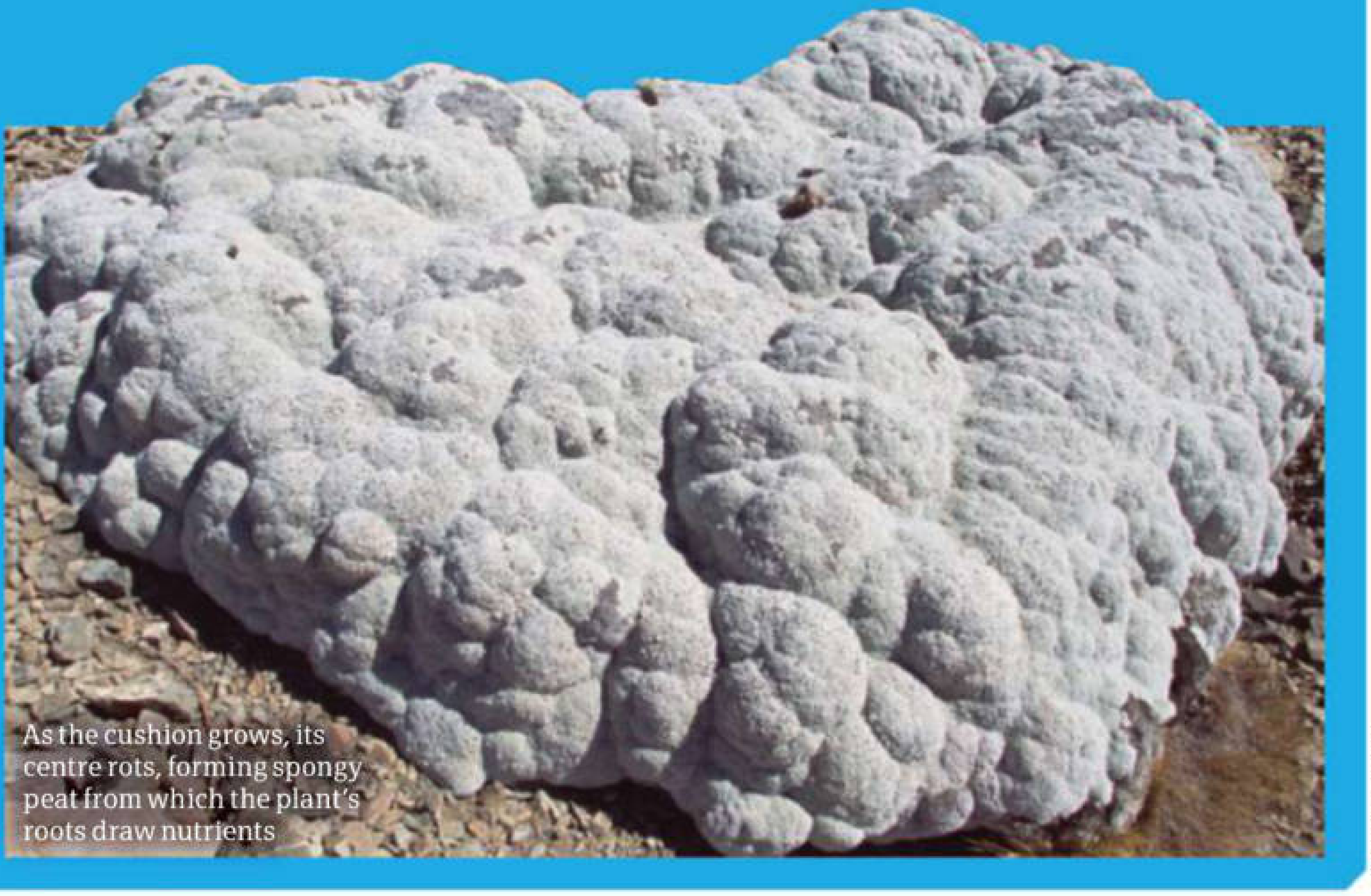
How vegetable sheep survive

High in New Zealand's mountains grow remarkable plants whose woolly hummocks resemble flocks of sheep

About 2,000 metres (6,650 feet) up in the mountains of New Zealand's South Island, grey shapes stand like a flock of unmoving sheep. These rounded, ovine cushions are actually Raoulia plants, covered in woolly leaves; they are more commonly known as vegetable sheep because of their fluffy whitish appearance.

Plants of the high mountains (called alpines) have to survive incredibly tough conditions. In winter they are frozen or buried under snow, while in summer, rain drains downhill and many hours of sunlight bake the land.

The cushion shape of Raoulia protects it from the weight of snow and it shelters from high winds by hugging the ground. Its woolly leaves form a winter blanket while their grey colour reflects the Sun's rays.


As the cushion grows, its centre rots, forming spongy peat from which the plant's roots draw nutrients

© Corbis; Thinkstock

Explaining rainforests

Receiving up to 2,000 millimetres of rainfall annually, and home to over 50 per cent of all Earth's species, the rainforests of our planet are a unique and life-abundant environment which still remain largely unobserved

Rainforests are found mainly in tropical regions near the equator where the climate is consistently hot and wet, allowing the rapid and prolific expansion of all forms of life, be it flora or fauna. From the heartlands of South America, through the jungles of Africa and India, to the north coast of Australia, the rainforests are a phenomenal breeding ground for evolutionary processes and major players in maintaining the world's natural cycles, responsible for over 28 per cent of its oxygen turnover.

However, despite their massive selection of indigenous life forms and overall importance to the Earth's oxygen production, the rainforests cover less than six per cent of its surface, a number that thanks to perpetual deforestation is reducing daily, causing many species to be driven to extinction and the climate of many parts of the globe to change radically. This is because despite initial appearances, rainforests are highly complex and intricate systems, consisting of multiple layers that shroud the plethora of activity that is undertaken in each. Indeed, it has only been thanks to recent advances in science and technology that scientists and biologists have been able to study the rainforests in their full glory, recording footage, imagery and results that have highlighted, if anything, how much we still don't understand about them.

Luckily, many discoveries have already been made in the rainforests of the Earth, each providing a snapshot into this alien world. Here we take a closer look at how the rainforests tick, with specific emphasis on their makeup, diverse species of plants and animals, natural processes and the threat to them from deforestation.

Lying around is just so tiring

©Thinkstock

Many species of parrot dwell in rainforests

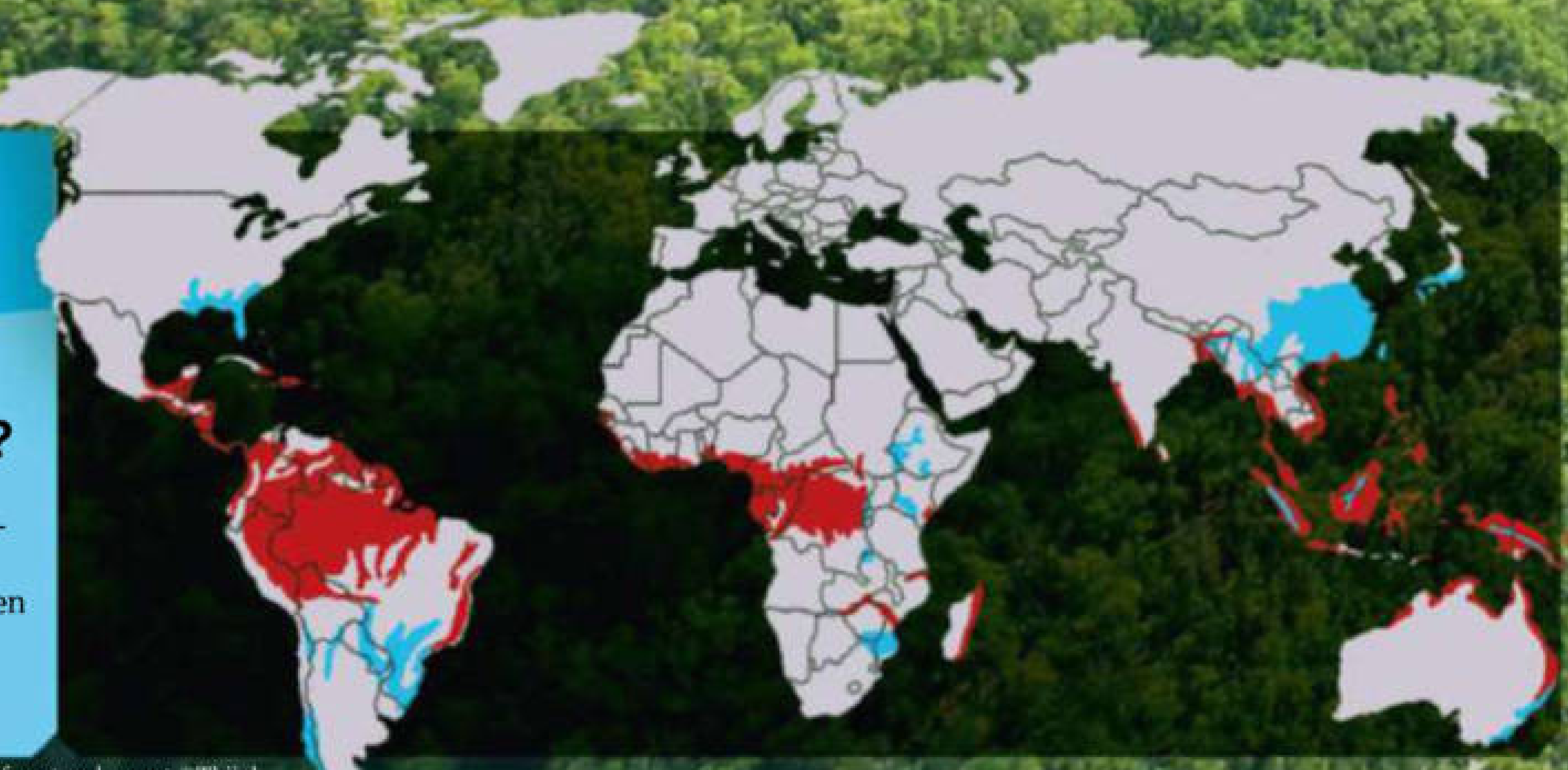
ON THE MAP

Where do the rainforests grow?

There are two types of rainforest, tropical and sub-tropical. Where they are situated on Earth can be seen on the adjacent map.

🟦 Sub-tropical

🟥 Tropical



Rainforest and parrot ©Thijnk. Map © Dennis Toran

The layers of rainforests

Uncovering life below the surface

EMERGENT LAYER

Height: 70-80m

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The highest level of any rainforest is the emergent layer, consisting of large (70-80 metre tall), spaced-out trees that reach far above the general canopy. These giants of the forest are characterised by their umbrella-type tops, perfect for catching light, as well as their super-thick trunks, ideal for keeping them upright when strong winds hit their exposed upper extremities. The emergent layer is home to many species of bird, insect and mammal, including eagles, monkeys and butterflies. However, due to its height and direct exposure to the Sun and high winds, the emergent layer houses only a fraction of the life that can be found in a rainforest.

CANOPY LAYER

Height: 35-40m

Estimated to house over 50 per cent of all plant species on Earth, the canopy layer is one of the densest layers of biodiversity to be found in a rainforest. The canopy layer is similar in fauna to the emergent layer, but far more diverse due to shade, moisture and moderate temperatures. It mainly consists of a thick-layered system of vines and branches where animals shelter from the Sun's rays. Examples of animals that live in the canopy layer include sloths, parrots and toucans.

UNDERSTORY LAYER

Height: 0.5-35m

Directly beneath the canopy layer and on top of the forest floor lies the understory layer, a dark, dense, humid maze of shrubs, vines and broadleaf trees. Home to animals such as the snakes, jaguars and lizards, the understory layer is one of the most hostile of all, where the battle for survival is fierce. Very little light manages to break down to this level thanks to the overarching canopy, causing many plants and trees to grow large leaves to maximise whatever light they can get. Insect life is prolific at this level, with leaf-cutter ants, spiders, mosquitos and moths a common sight.

FOREST FLOOR

Height: 0-0.5m

The lowest layer in any rainforest is the forest floor, a ground layer where the soil quality is exceptionally poor due to the almost total lack of sunlight. This level is prolific, however, in mosses, fungi and microorganisms (such as termites and earthworms).

The animals of the rainforests

The rainforests of the globe are inhabited by some of its most amazing creatures

Rainforests are tremendously rich in animal life thanks to their humid, life-abundant climates. A usual population for an area of rainforest can contain insects, reptiles, amphibians, birds, arachnids and mammals, with a diversity across all its layers unmatched anywhere else on the planet.

Among the most exotic inhabitants are the toucans, brightly coloured birds characterised by their enormous rainbow bills, ideal for reaching for fruit and other food in hard-to-reach places, as well as to intimidate potential predators.

Another species of animal the eastern rainforests boast is the endangered Bengal tiger, of which there are only about 2,000 left in the wild. The second largest tiger on Earth, Bengal tigers can grow up to over three metres and their average weight is 221 kilograms. As obligate carnivores, the amount of meat required to feed a Bengal is staggering (they can wallop 20kg in a single sitting), something that they achieve through a consistent diet of boars, deer, monkeys, birds and, in extreme circumstances, elephants, bears, leopards, wolves and even humans.

Three-toed sloths can also be found in the rainforest. Famously slow moving (they have a top speed of just 0.24km/h), it is an almost totally tree-dwelling species, with its entire body built to hang from thick branches and vines. These sloths tend to inhabit the understory layer of the forest.

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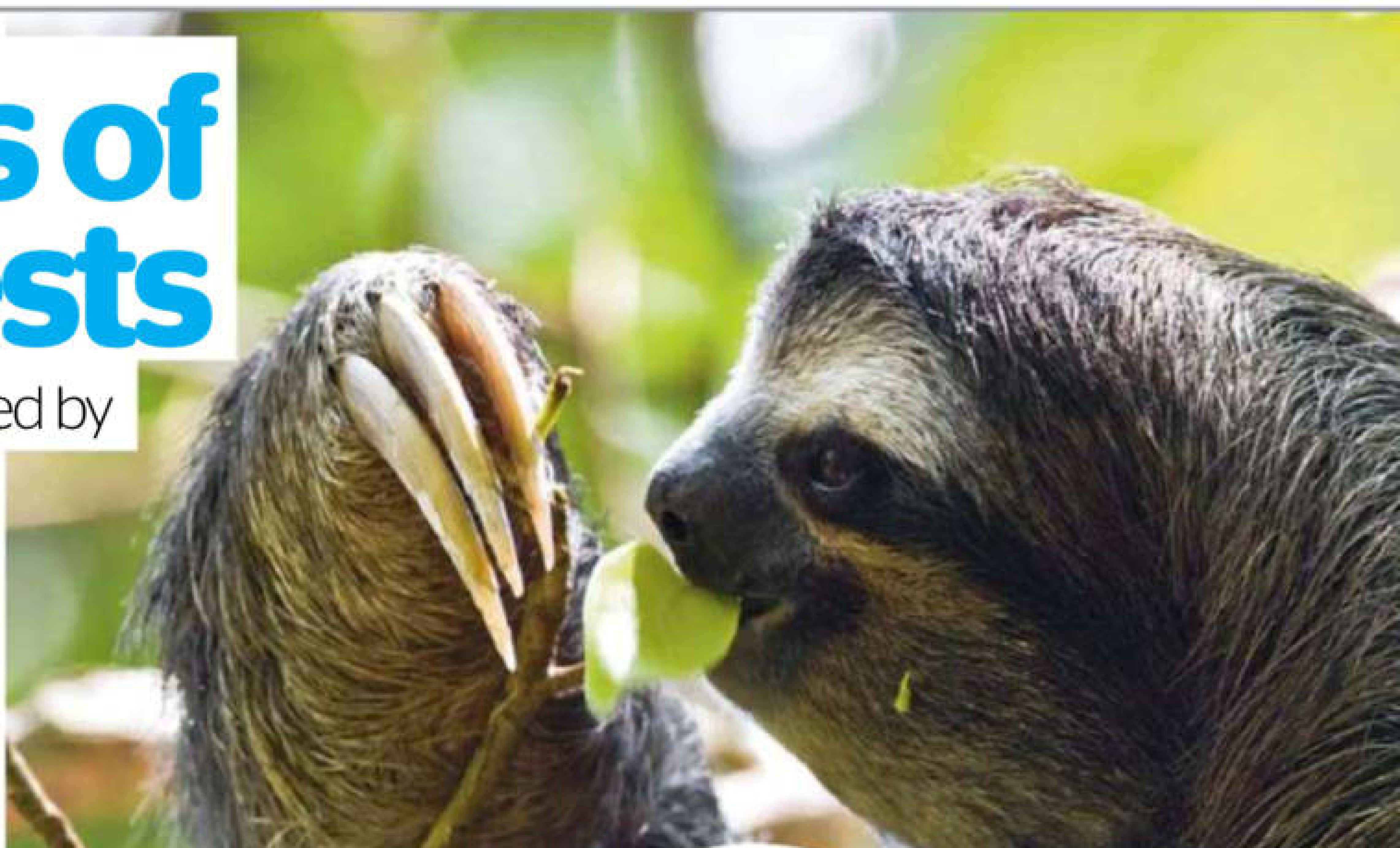

Never one to rush through a meal…

A Bengal tiger stalks through the rainforest

Numerous frogs live in rainforests; many are poisonous

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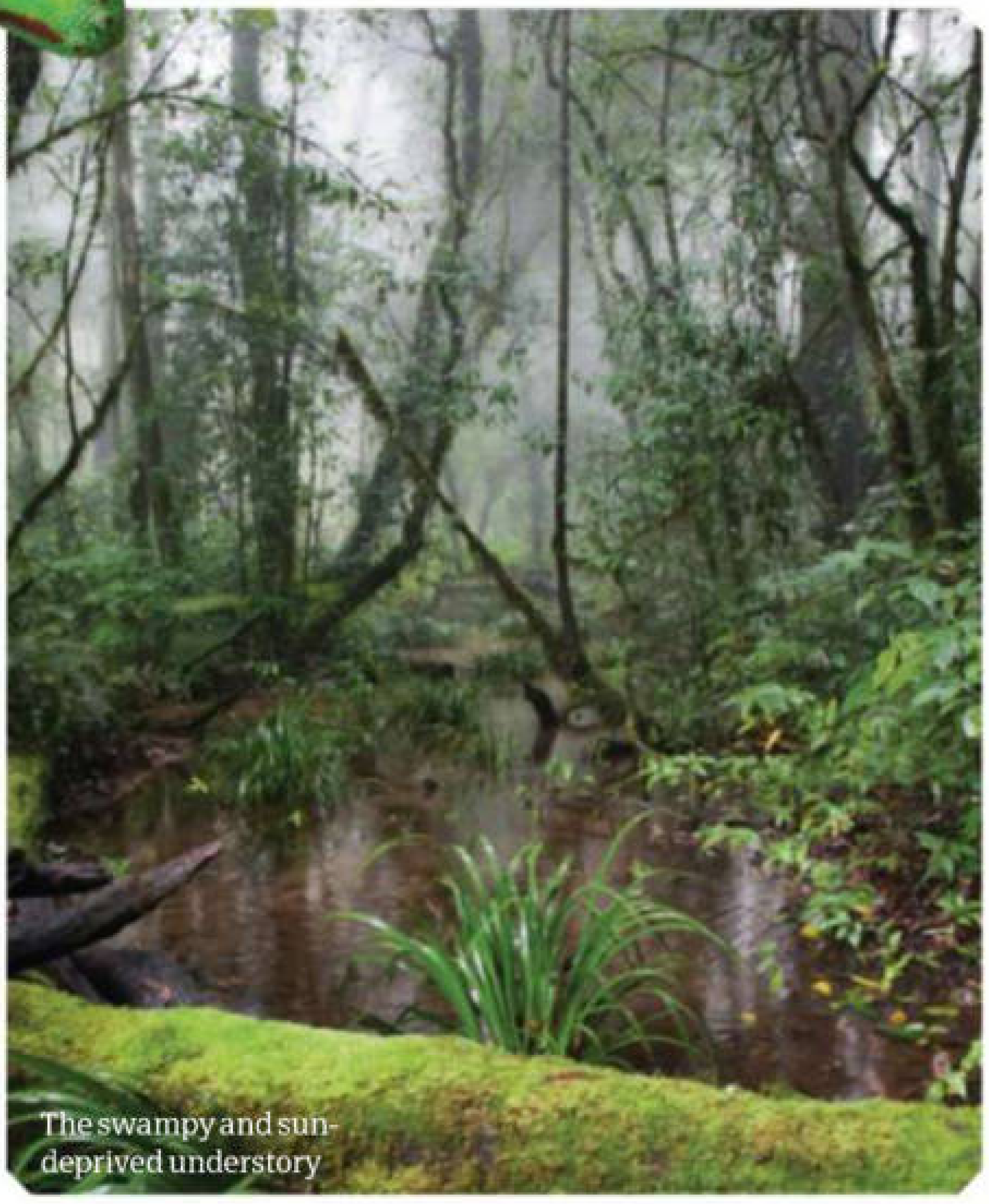


The swampy and sun-deprived understory

The plants of the rainforests

Known as the 'world's largest pharmacy', many of the natural medicines we use originate here

The amounts of chemicals that can be found in the plants of the rainforests are quite staggering. Take the cocoa tree for example, which produces more than 150 chemicals in its leaves, fruit, seeds and bark. The chemicals of this highly medical plant have been used to treat anxiety, fever and kidney stones among other things, as well as holding polyphenols that reduce the chance of cardiovascular disease and even cancer.

Another much-used medicinal plant from the Amazonian rainforest is the Achiote. Parts of this small shrub/tree can be used to make medical remedies for conditions such as leprosy, tonsillitis, pleurisy and apnoea. In addition, the sap from the Achiote's fruit is

Deforestation and climate change

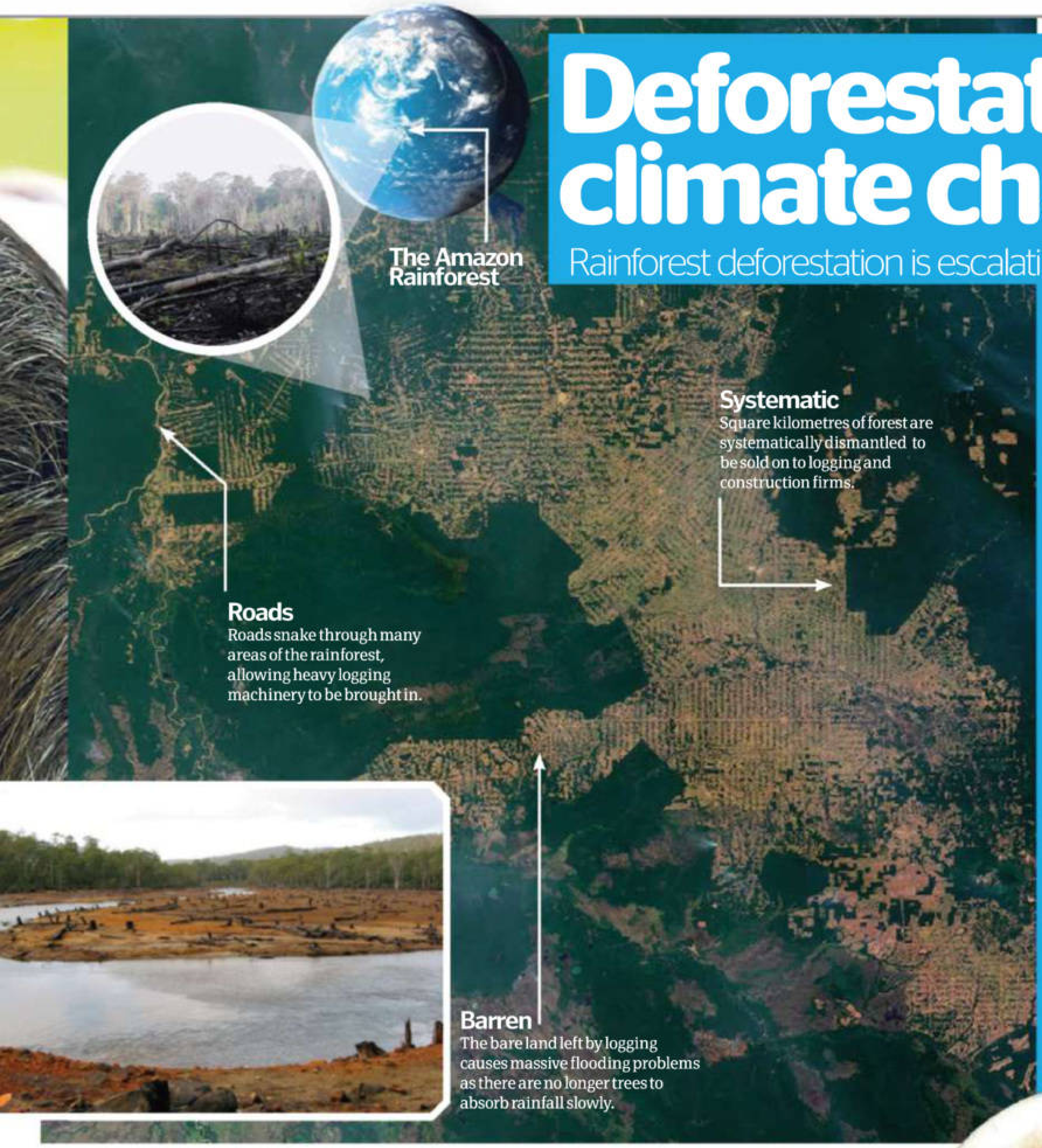
Rainforest deforestation is escalating at an alarming rate

The effects on the Earth that deforestation brings are severe, with regional and global climate changing wildly, flooding more frequent, and the extinction of thousands of species of animals and plants. The causes of this destruction are many, with logging and cattle ranching the most serious.

Logging is the systematic processing of hectares of trees to be used in local and international markets, and it is estimated by conservationists that over 75 per cent of the world's forests have been destroyed or degraded by logging.

Cattle ranching also massively eats away at the borders of rainforests, and is increasing flood-prone areas greatly. This is because when ranchers cut down trees to create areas for their animals to pasture, they remove the sponge effect the rainforest provides, so instead of absorbing the large amount of rain the forest receives and distributing it slowly, the newly stripped area just floods and channels quickly off into nearby rivers which then also flood.

The reduction in trees also has an impact on both the local and global climate, because each time a part of rainforest is lost the net oxygen output from the area, due to photosynthesis, is reduced even further. Biosequestration (the capture and storage of greenhouse gases) is also reduced, as is the excess quantities of carbon produced under the rainforest, an important source of fuel for the future wellbeing of Earth.



The Amazon Rainforest

Systematic
Square kilometres of forest are systematically dismantled to be sold on to logging and construction firms.

Roads
Roads snake through many areas of the rainforest, allowing heavy logging machinery to be brought in.

Barren
The bare land left by logging causes massive flooding problems as there are no longer trees to absorb rainfall slowly.

> "Pitchers have evolved this taste for blood due to the harsh conditions in which they grow"

used frequently to treat type 2 diabetes. Historically, records have shown that the native peoples of South America used the properties of the Achiote to lower blood pressure and as an insect repellent.

However, not all plants are medicinal, with many of the most aggressive and carnivorous species thriving in the humid, moisture-abundant conditions. Among the most famous of these are the carnivorous Venus flytrap and Pitcher plant, both of which devour numerous insects, reptiles and small mammals.

The Pitcher plant, which can be found mainly on the island of Borneo, traps its prey by luring insects and small animals into its conical body through its attractive appearance and corpse-like smell. Once inside the victim slips into a pool of lethal liquid at its bottom due to slick inner walls, before drowning and being slowly digested. Pitchers have evolved this unnatural taste for blood due to the harsh conditions in which they grow, only found on the forest floor layer of a rainforest.

The Venus flytrap, on the other hand, devours prey in a far more elegant manner. Luring prey into its waiting jaw through the sweet sticky nectar within, the flytrap then snaps shut on its prey when minuscule hairs are brushed against. The closing of its two leaves over the insect takes only a fraction of a second, and while certain bugs may escape, the majority get encased and slowly digested.

There are even plants that can eat rats whole!

How plants work

Could you stay put in your birthplace for hundreds of years, surviving off whatever happens to be around?

Truly, it's not easy being green. But plants not only survive, they thrive all over the globe, without the benefit of muscles, brains or personalities. It's a good thing they do: plants head up nearly all food chains, pump out the oxygen we breathe, hold off erosion and filter pollutants out of the atmosphere. Over the past 3.5 billion years, they've diversified into an estimated 320,000-430,000 separate species, with more coming to light every year.

All this stems from one neat trick: harnessing the Sun's energy to power a built-in food factory. Through this process, called photosynthesis, plants combine carbon dioxide with water to create carbohydrates that they use to grow and reproduce.

The earliest plants, similar to today's algae, didn't do much other than photosynthesise. They floated around in the ocean, soaking up water and rays and reproducing asexually when the mood struck them. Then, around 500 million years ago, plants evolved to live on the land, to obtain the power boost of more abundant sunlight. The first landlubber plants still needed to stay wet all over, however, so they were confined to perpetually damp areas. Today's mosses, liverworts, and hornworts have the same limitations.

Things got more exciting 90 million years later, when plants went vascular. Vascular plants have tissue structures that can distribute water and nutrients absorbed by one part of the body to the rest of the body. Instead of spending its days soaking in a puddle, a vascular plant can grow roots down into the ground to soak up water and minerals while sending shoots up into the dry air, topped with leaves that soak up sunshine to power the food factory.

Plants can store this food in their roots, in the form of root tubers, like carrots and sweet potatoes. Above ground, vascular plants protect themselves and retain their water supply by using a waxy, waterproof covering called cuticle. Cuticle makes plants hearty enough to reach high up into the air or spread far along the ground.

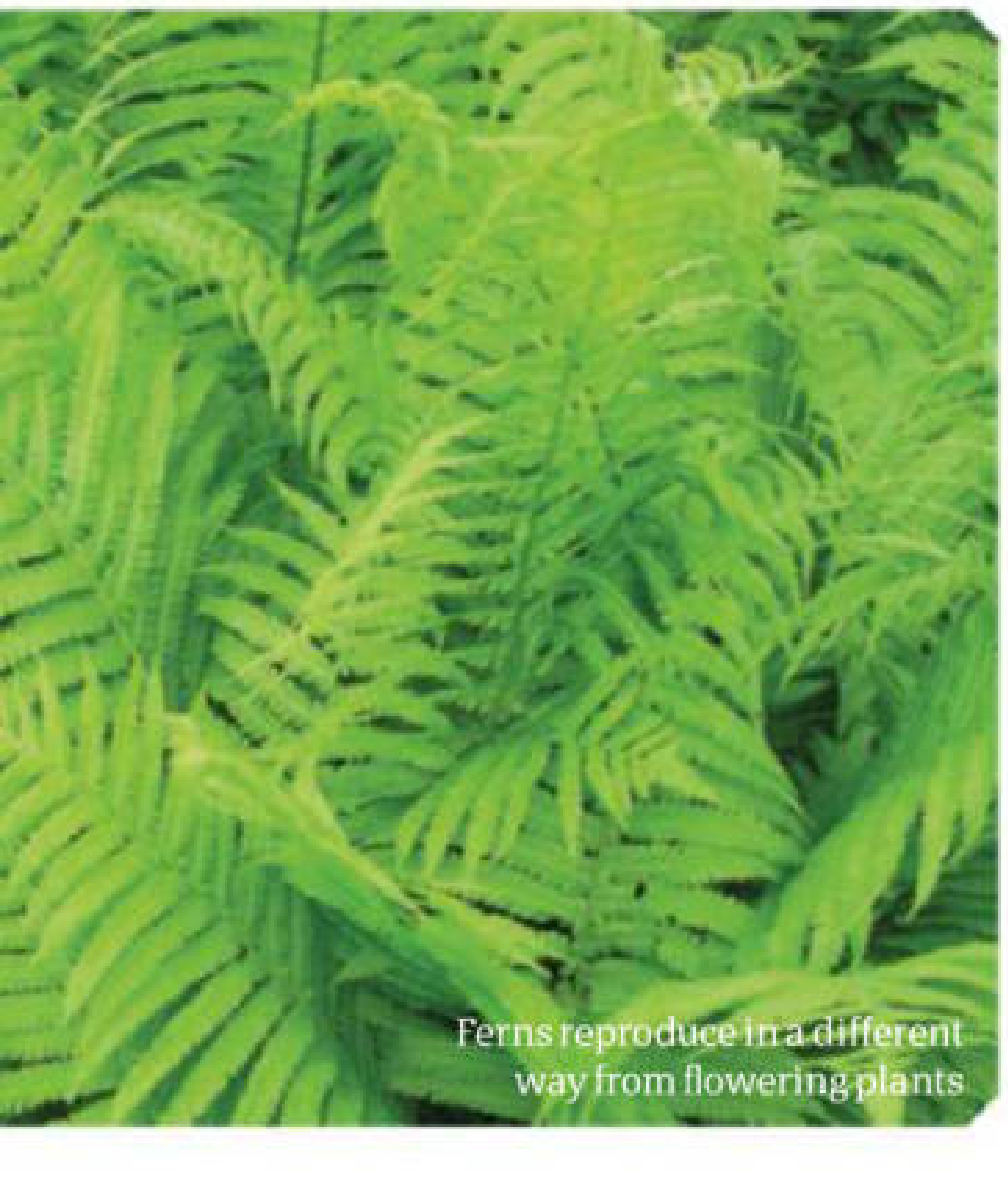
Plants grow at meristems, areas with cells that are capable of division – that is, making new cells. Hormones control this cell division to grow particular forms, like leaves, as well as controlling the

direction of growth, guided by what the plant 'senses'. Based on the settling of starch grains that indicate the direction of gravity, the growth hormone auxin drives stems to grow up towards the sky and roots to grow down towards water. Then, plants actually turn leaves toward the Sun. Triggered by light-sensitive cells that effectively 'see' light, the hormone auxin causes more cells to grow on the dimmer side of a stem, making the stem and attached leaf bend towards sunlight. Similarly, vines automatically curl when they come across a larger plant, causing them to wrap and climb.

Plants switch sexual orientation every generation. Each sporophyte generation produces male and female spores, which asexually yield male and female plants. In this gametophyte generation, males produce sperm and females produce eggs, which join up to create new sporophyte plants. Typically, the sporophyte generation is a large, familiar plant, while the gametophyte generation is tiny. For example, pollen is tiny male plants in the gametophyte generation. The tiny males and females produce an embryo, or seed.

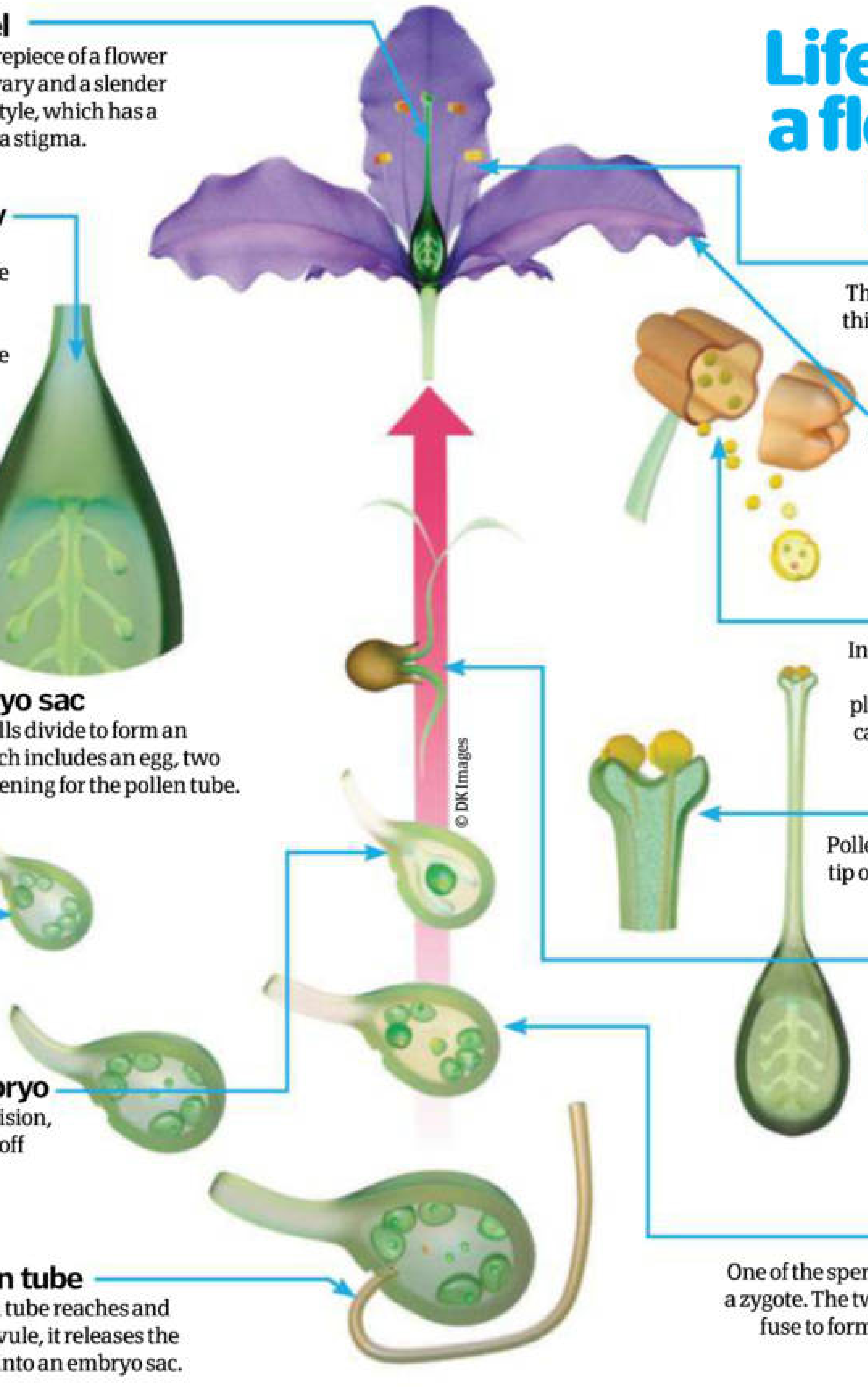
When you can't walk, spreading your seed requires some creativity. For example, flowering plants attract insects with nectar, and then coat their legs with pollen to carry to the next plant. Plants also develop tasty fruits around plant seeds to entice animals to eat them and swallow the seeds, and then defecate those seeds miles away.

Plants enrich every corner of human life, even beyond food and oxygen. From invaluable herbs – plants with medicinal or flavour value – to towering trees made from woody tissue, our original go-to construction material, plants prop up our civilisation. High-five one today.



Ferns reproduce in a different way from flowering plants

Life cycle of a flowering plant



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1. The carpel
The female centrepiece of a flower comprises the ovary and a slender neck called the style, which has a sticky top called a stigma.

2. The stamen
The flower's male members include this stalk-like filament, topped with the pollen-producing anther.

3. The petals
Flower petals are like a neon sign designed to attract insects that come for the free nectar, then unintentionally carry pollen to other flowers.

4. Gametophytes
Inside each anther, gametophytes – technically microscopic male plants – are encased in pollen grain capsules. Each includes two sperm cells and a tube cell.

5. The stigma
Pollen grains stick to the stigma at the tip of the carpel, and produce a pollen tube down the style and ovary.

6. The ovary
The ovary includes multiple compartments called ovules, each housing one gametophyte – technically, a tiny female plant.

7. The embryo sac
In each ovule, cells divide to form an embryo sac, which includes an egg, two nuclei and an opening for the pollen tube.

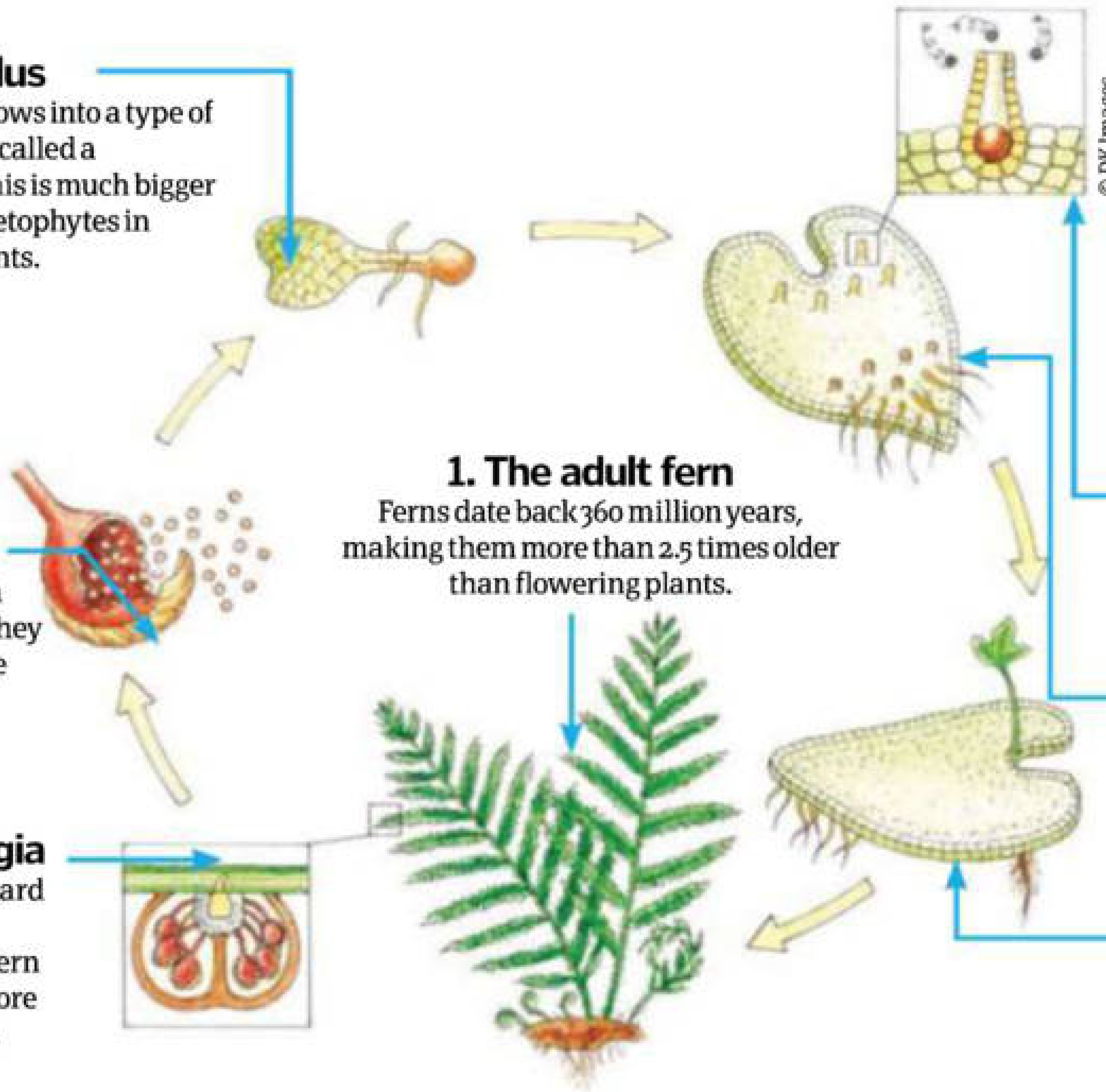
8. The pollen tube
When the pollen tube reaches and penetrates the ovule, it releases the two sperm cells into an embryo sac.

9. The zygote
One of the sperm cells fertilises the egg, creating a zygote. The two nuclei and the other sperm cell fuse to form a food supply called endosperm.

10. The embryo
Through cell division, the zygote feeds off the endosperm.

11. The seed
The casing surrounding the ovule hardens around the embryo, to form a seed. When it has ample warmth, moisture, and oxygen (typically in the spring), the seed germinates – that is, begins to grow into an adult plant.

Life cycle of a fern



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1. The adult fern
Ferns date back 360 million years, making them more than 2.5 times older than flowering plants.

2. Sporangia
Inside these hard pods on the underside of fern fronds, the spore cells multiply.

3. Spores
When enough spores form, they burst open the pod and disperse.

4. Prothallus
Each spore grows into a type of gametophyte called a prothallus. This is much bigger than the gametophytes in flowering plants.

5. Mature gametophyte
The prothallus grows both a female sex organ (the archegonia) and a male sex organ (the antherida), which produces sperm.

6. Archegonia
Sperm from another prothallus fertilises the egg inside the archegonia, to form a zygote.

7. Young fern
The zygote grows into a young fern, and the prothallus structure withers away.

Most unusual plants

The sensitive plant

Touch a leaf on the sensitive plant, also known as mimosa pudica, and an electrical current activates sudden water loss, causing leaves to drop abruptly. This imitation of an animal scares pests away.

© Pharaoh han 2009

Myrmecophytes

Many species, collectively known as myrmecophytes, have evolved to be ideal homes for ant colonies. In return, the ants viciously attack any threats to the plant.

Sumatran corpse flower

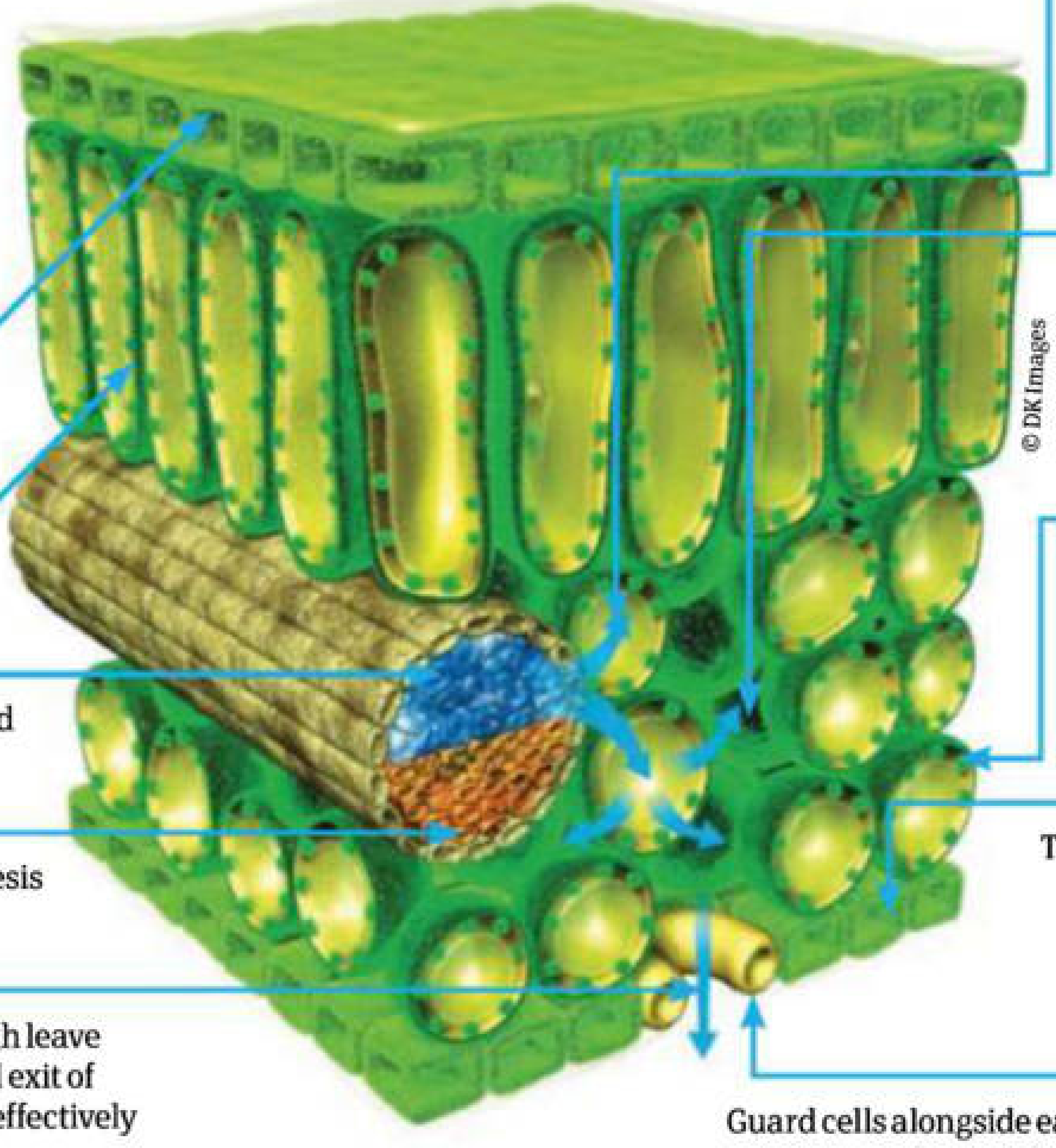
The world's largest flower can grow to be 0.9m (3ft) wide and 24 pounds. It mimics the smell of rotting meat in order to attract carrion-eating insects, which will inadvertently spread its pollen.

Snowdonia hawkweed

This Welsh flower is possibly the world's rarest plant. Botanists thought it extinct in the early-Fifties, but in 2002 it made a surprise reappearance near Bethesda.

Plant plumbing:
How transport works

Internal transportation systems in plants move water, food and other nutrients between roots, stems and leaves. This system is the key adaptation that allowed plants to evolve elaborate shapes and towering forms.



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Upper epidermis
The waxy cuticle on the epidermis keeps the plant from drying out.

Palisade mesophyll
These cells are rich in chloroplasts, which are integral in photosynthesis.

Xylem vessel
These vessels carry water, with dissolved minerals, from the roots to leaves.

Phloem vessel
These carry food created in photosynthesis from leaves to the rest of the plant.

Diffusion
This water vapour exits the plant through leave openings called stomata. This continual exit of water creates negative pressure, which effectively pulls water up the xylem from the roots.

Movement of water
Water moves from the xylem vessels, which run from the roots to leaves, into the mesophyll cells.

Evaporation
Water along the walls of the mesophyll cells evaporates, forming water vapour.

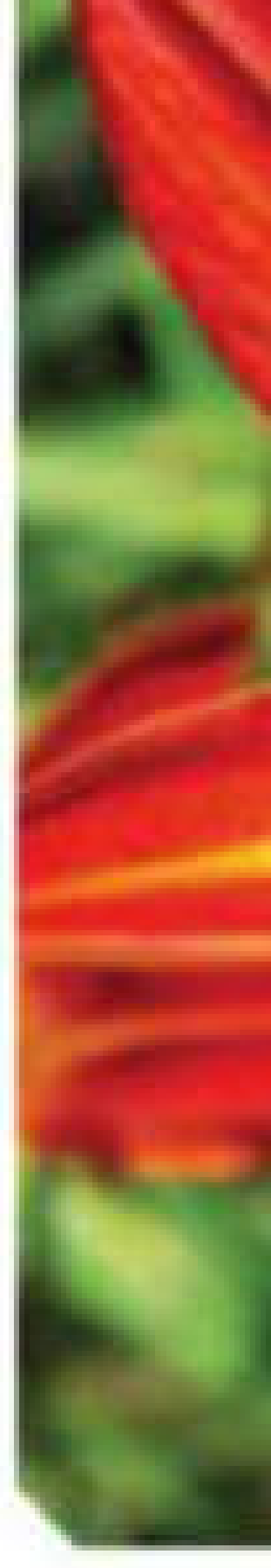
Spongy mesophyll
Mesophyll cells fit together to form most of the tissue in a leaf.

Lower epidermis
The lower epidermis can be thinner than the upper epidermis, since it doesn't get direct sunlight.

Stoma
Guard cells alongside each stoma (pore in the leaf) open when sunlight and humidity are high.

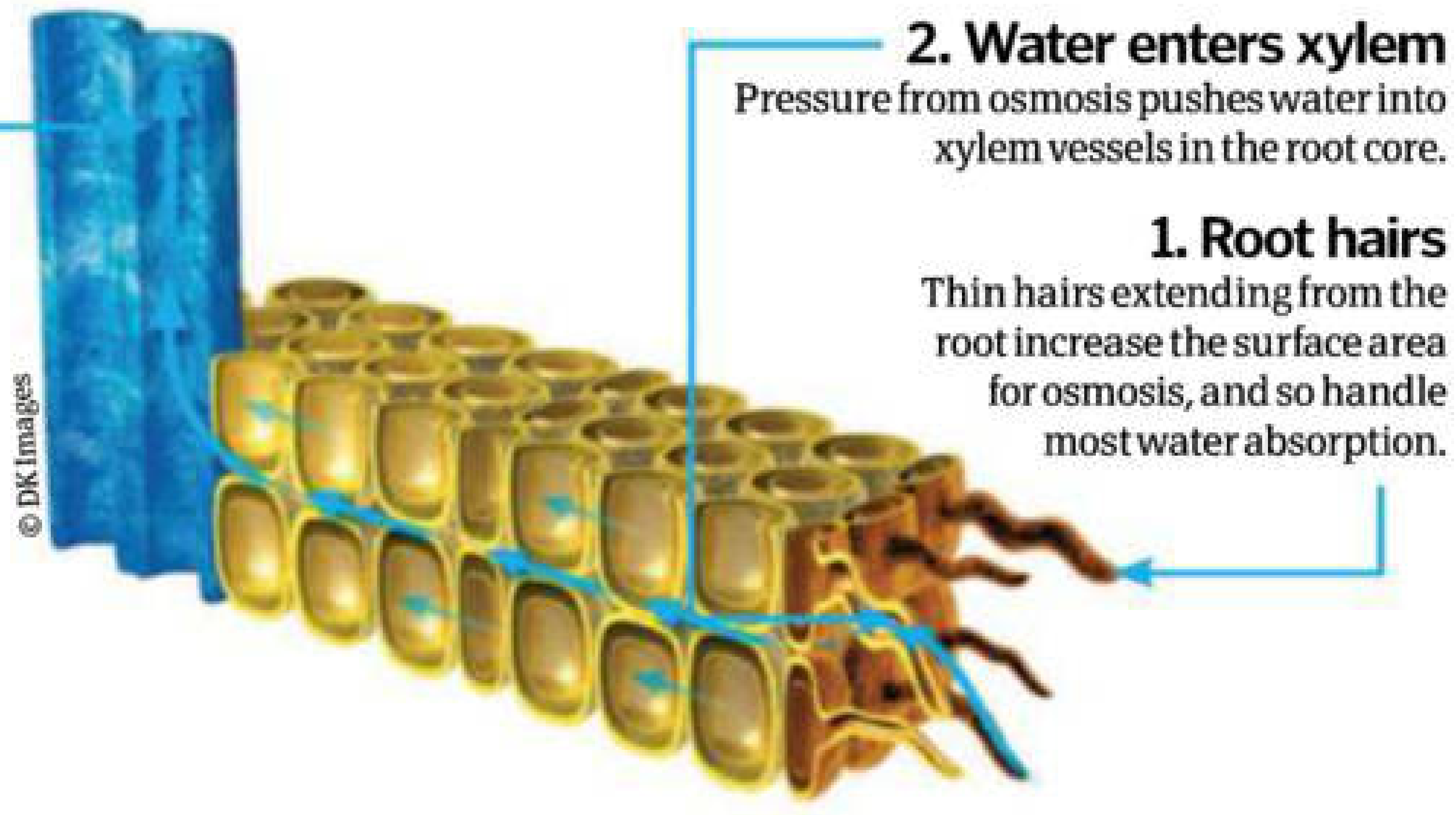
Flower stigmas come in various shapes

Insects seeking nectar pick up pollen on their legs



The root of it:
How absorption works

Roots soak up water through osmosis – the drive for water to move through a cell membrane from a less concentrated solution to a more concentrated solution, in order to achieve equilibrium. Cells in roots will have a higher concentration than the surrounding water in the soil, so the water then flows into the root.



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3. Water enters the stem
Water continues flowing through the xylem, up into the above-ground stem, helped along by negative pressure in the leaves, created by evaporating water.

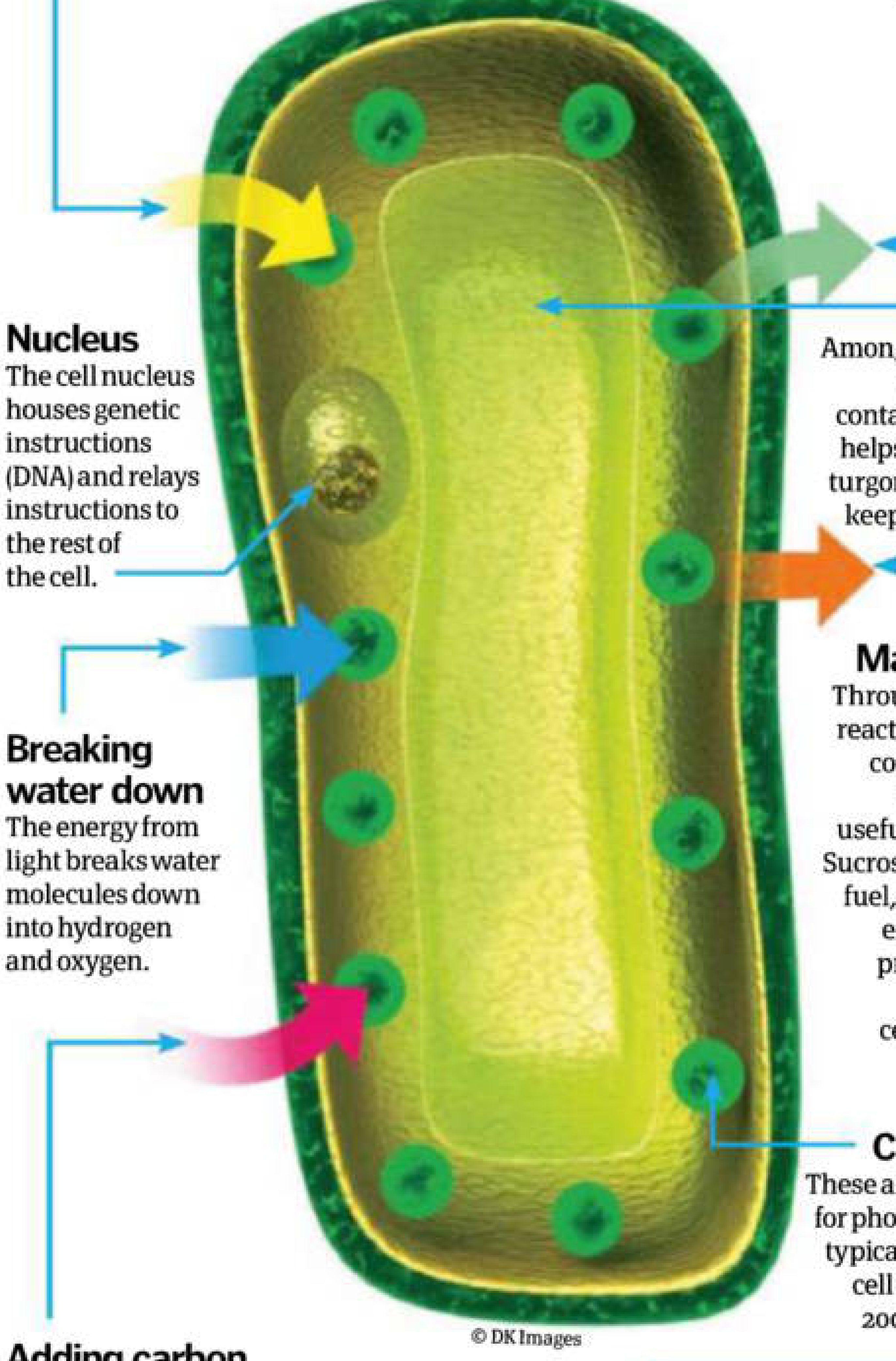
2. Water enters xylem
Pressure from osmosis pushes water into xylem vessels in the root core.

1. Root hairs
Thin hairs extending from the root increase the surface area for osmosis, and so handle most water absorption.

Inside the food factory:
How photosynthesis works

In Greek, photosynthesis means 'putting together' (synthesis) using 'light' (photo), and that's a decent summary of what it's all about. However, photosynthesis doesn't actually turn light into food, as you sometimes hear; it's the power source for a chemical reaction that turns carbon dioxide and water into food.

The energy of light protons temporarily boosts the electrons in pigment molecules to a higher energy level. In other words, they generate an electrical charge. The predominant pigment in plants – chlorophyll – primarily absorbs blue, red, and violet light, while reflecting green light (hence, the green colour). In some leaves, chlorophyll breaks down in the autumn, revealing secondary pigments that reflect yellows, reds, and purples. Pigments are part of specialised organelles called chloroplasts, which transfer the energy of excited electrons in pigments to molecules and enzymes that carry out the photosynthesis chemical reaction.



Harnessing sunlight
Chlorophyll and other pigments absorb energy of light photons from the Sun.

Expelling oxygen
The oxygen from the water isn't necessary to make food, so the plant releases it through pores called stomata.

Nucleus
The cell nucleus houses genetic instructions (DNA) and relays instructions to the rest of the cell.

Vacuole
Among other things, this organelle contains water that helps maintain the turgor pressure that keeps plants erect.

Breaking water down
The energy from light breaks water molecules down into hydrogen and oxygen.

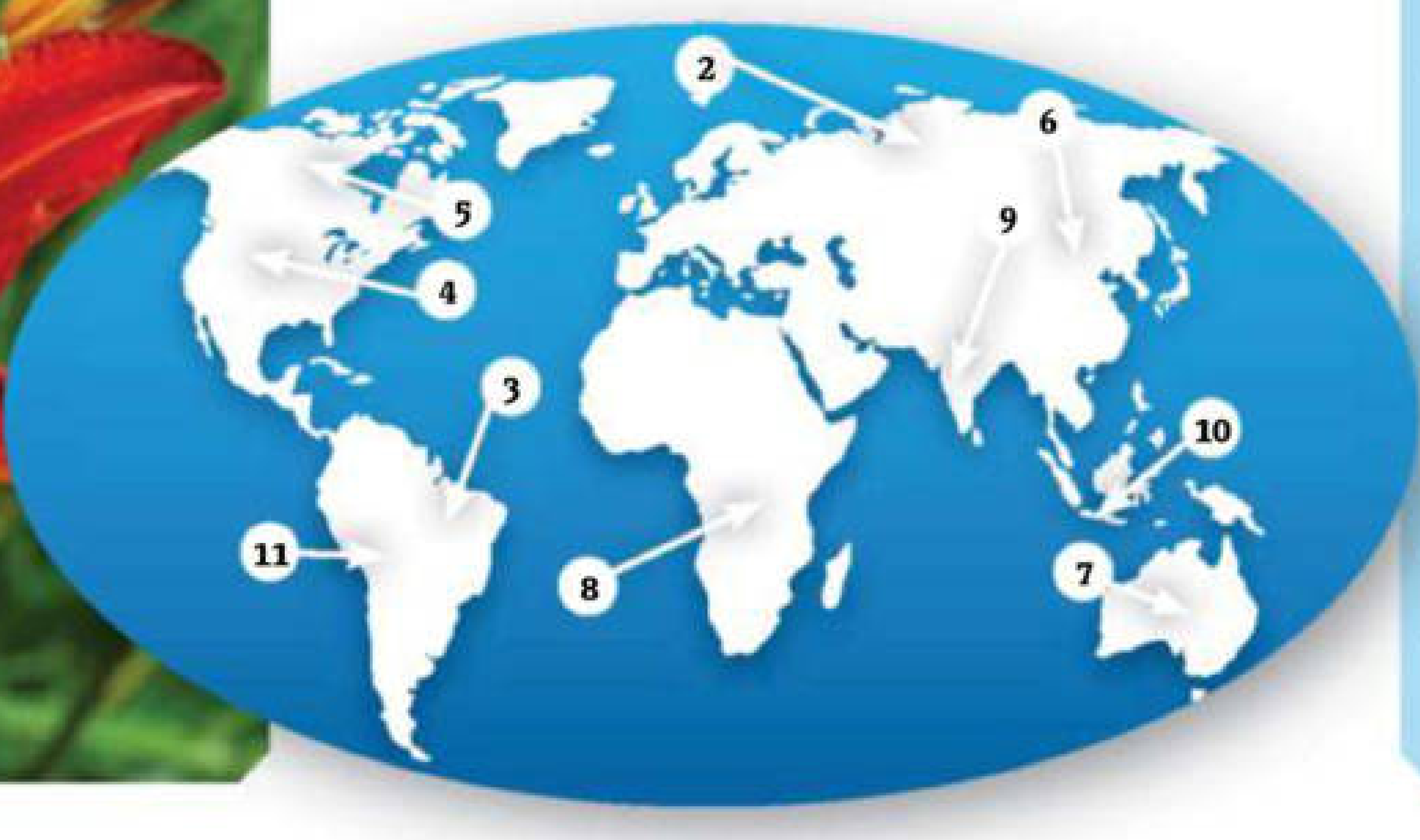
Making food
Through additional reactions, the plant converts glucose into a range of useful compounds. Sucrose acts as plant fuel, starches store energy for later, protein aids cell growth, and cellulose builds cell walls.

Chloroplast
These are the engines for photosynthesis. A typical leaf palisade cell includes up to 200 chloroplasts.

Adding carbon dioxide
Plants get all the CO_2 they need from the air. CO_2 combines with hydrogen to make glucose, a simple sugar.

© DK Images

Colourful petals are designed to attract insects



ON THE MAP

How much of the planet is covered by forest?

40 million sq km (15,444,100 sq miles), or a third of the Earth's land area, is covered by forests.

1 34% Rest of the world
2 20% Russian Federation
3 12% Brazil
4 8% US
5 8% Canada
6 5% China
7 4% Australia
8 3% Democratic Republic of Congo
9 2% India
10 2% Indonesia
11 2% Peru

© Walter Siegmund 2009

Bunchberry dogwood

This shrub holds the 'fastest plant' record. When its flower opens, stamens fling out like a catapult, propelling pollen at 800 times the g-force astronauts experience.

© Dr David Midgley

Parachute flowers

The different species of parachute flower have long flower tubes lined with inward pointing hairs that temporarily hold insects trapped, to ensure they end up covered in pollen before exiting.

Welwitschia mirabilis

This so-called 'living fossil' plant of the Namib desert in Africa grows only two leaves, over hundreds of years. They grow continuously, however, and can extend more than 4 metres (13 feet).

© Science Photo Library

Flypaper plants

Also known as butterworts, these plants are coated in super-sticky digestive enzymes that absorb nutrients from all manner of bugs that happen to get trapped.

How rivers

The river's fascinating processes and intriguing features from start to finish

Beginning life in the mountains, rivers form from streams created through precipitation or springs of water that are sourced from groundwater that has percolated the earth. These streams, known as tributaries, then flow rapidly through V-shaped valleys, over rocky terrain and over rock edges, where they're known as waterfalls. This is the first of three stages any river goes through and is known as the upper course or youth.

By the second stage, known as the middle course or maturity, many tributaries will have joined together to form the main body of water that makes up the river. The river meanders at a medium speed across narrow flood plains, which are areas of flat land lying either side of a river. Flood plains are formed when successive flooding causes sediment to be deposited on the banks.

As the river follows its course it carries with it a load, which is made up of rocks, stones, sand and other particles. It is the load that causes erosion as the materials crash against the banks of the river. The load is transported down the river in four ways, depending upon the size of the material. Traction is the rolling of the largest particles across the riverbed, whereas saltation is the bouncing of those slightly smaller. Finer materials are carried along through suspension and some are dissolved within the water and are moved through solution.

The final stage of a river is the lower course, and predictably is sometimes known as old age. By this time the river has slowed considerably as it heads towards the sea across broad flood plains, finally ending at what is known as the mouth – where the river finally joins the ocean. Deltas are formed as the river deposits its load.

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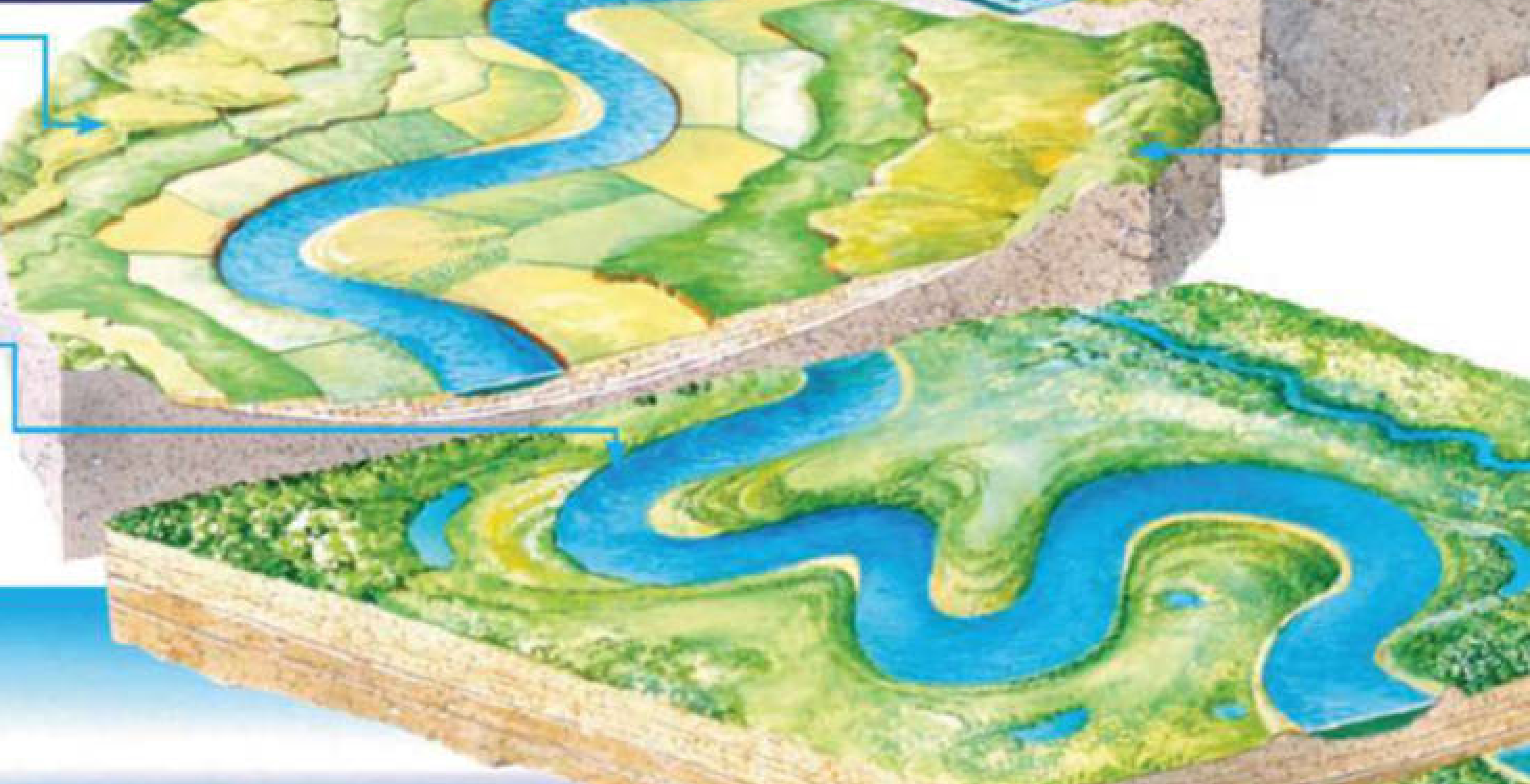


The river system

Flood plain
The flat land either side of the river is where floodwater goes and sediment is deposited when the river floods.

Meander
As the river travels its course its load erodes the sides and carves out bends that are known as meanders.

Delta
This is where the river slows down as it reaches the sea and as the water slows it deposits its load. This deposited sediment forms the delta.

Mouth
This is the end of the river, where it widens and joins with the sea. All rivers end this way.

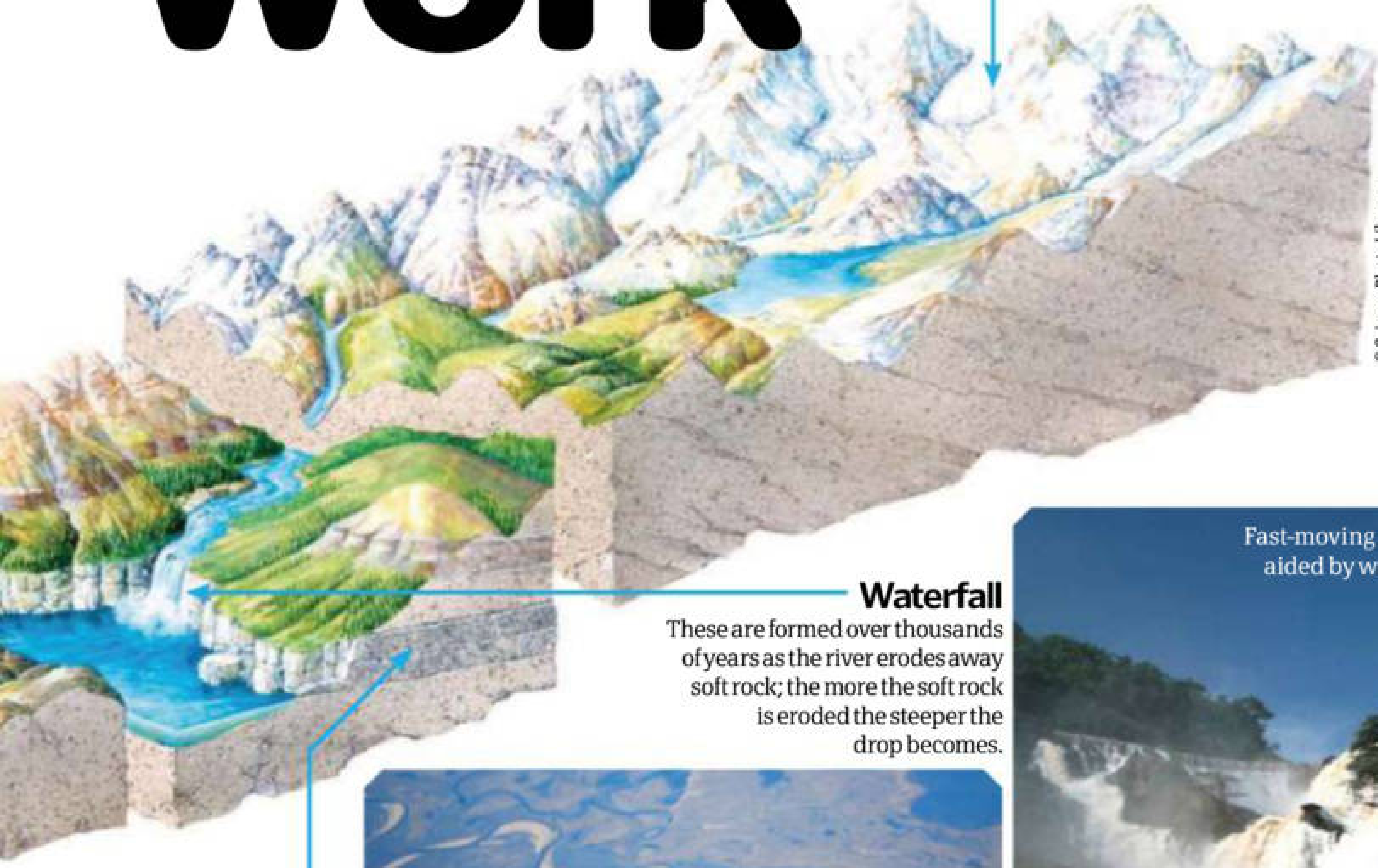
Deltas, estuaries and the river mouth

The mouth of a river signifies the end of its course and is where the river meets the sea. The 'D' shaped area of sediment that forms at the river mouth is called a delta. Deltas are built up from the bed as the river slows and deposits its load as it reaches the end of its course. The river tends to split as it travels over a delta.

Estuaries are also found at the mouth of a river. In these areas the fresh water of the river meets and mixes with the salt water of the sea. Estuaries are affected by the tide, and the combination of salt and fresh water provides a diverse habitat for many plants and animals.

The delta of the Atchafalaya River on the Gulf of Mexico

work



Source

It is here the river begins its life, in the form of small streams up in the mountains, which eventually come together to form the main body of the river.

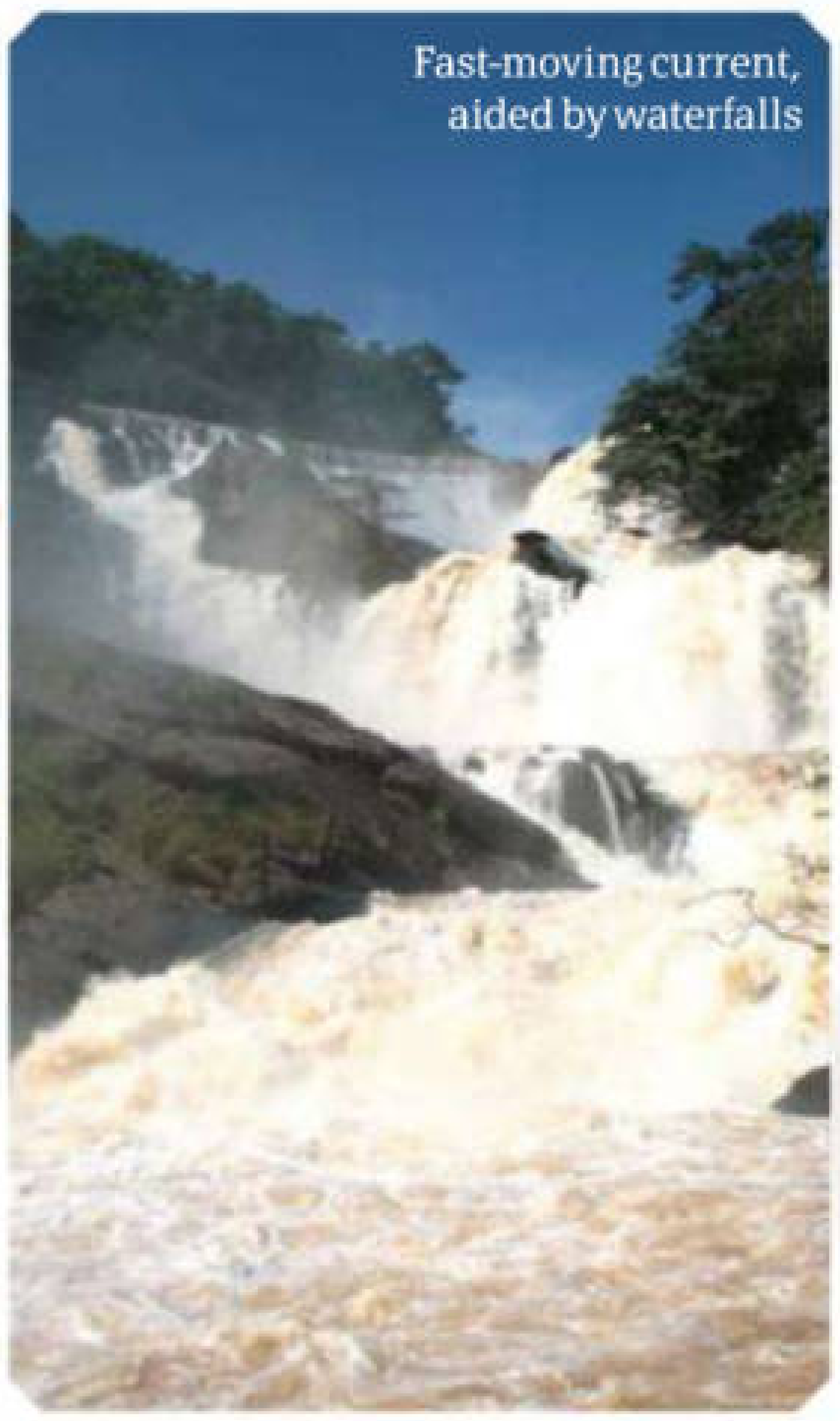
© Science Photo Library

Waterfall

These are formed over thousands of years as the river erodes away soft rock; the more the soft rock is eroded the steeper the drop becomes.

River basin

All of the land around the river is the river basin. The water drains from this land into the river.

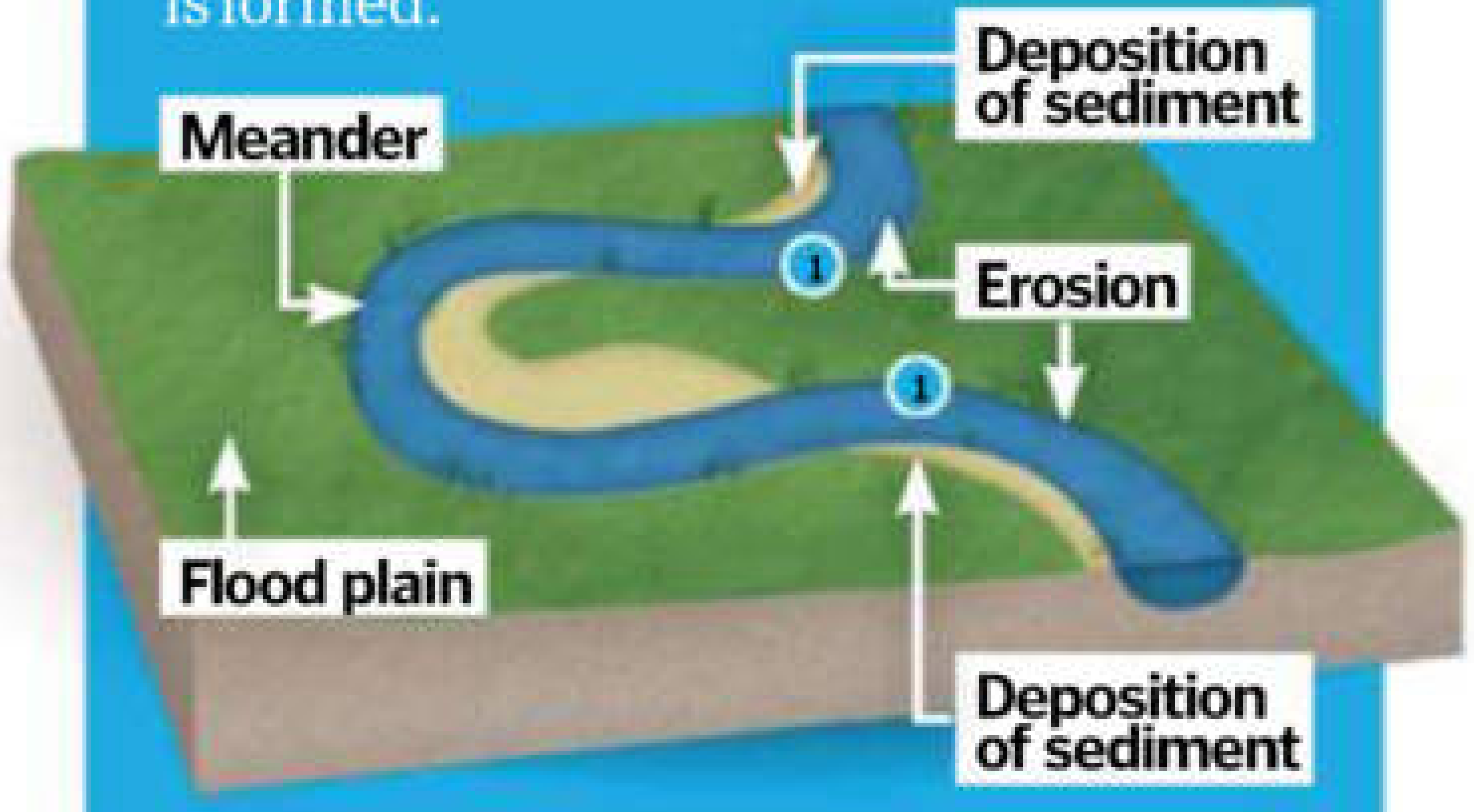


Fast-moving current, aided by waterfalls

A river in the Yamal Peninsula, Siberia that's produced oxbow lakes

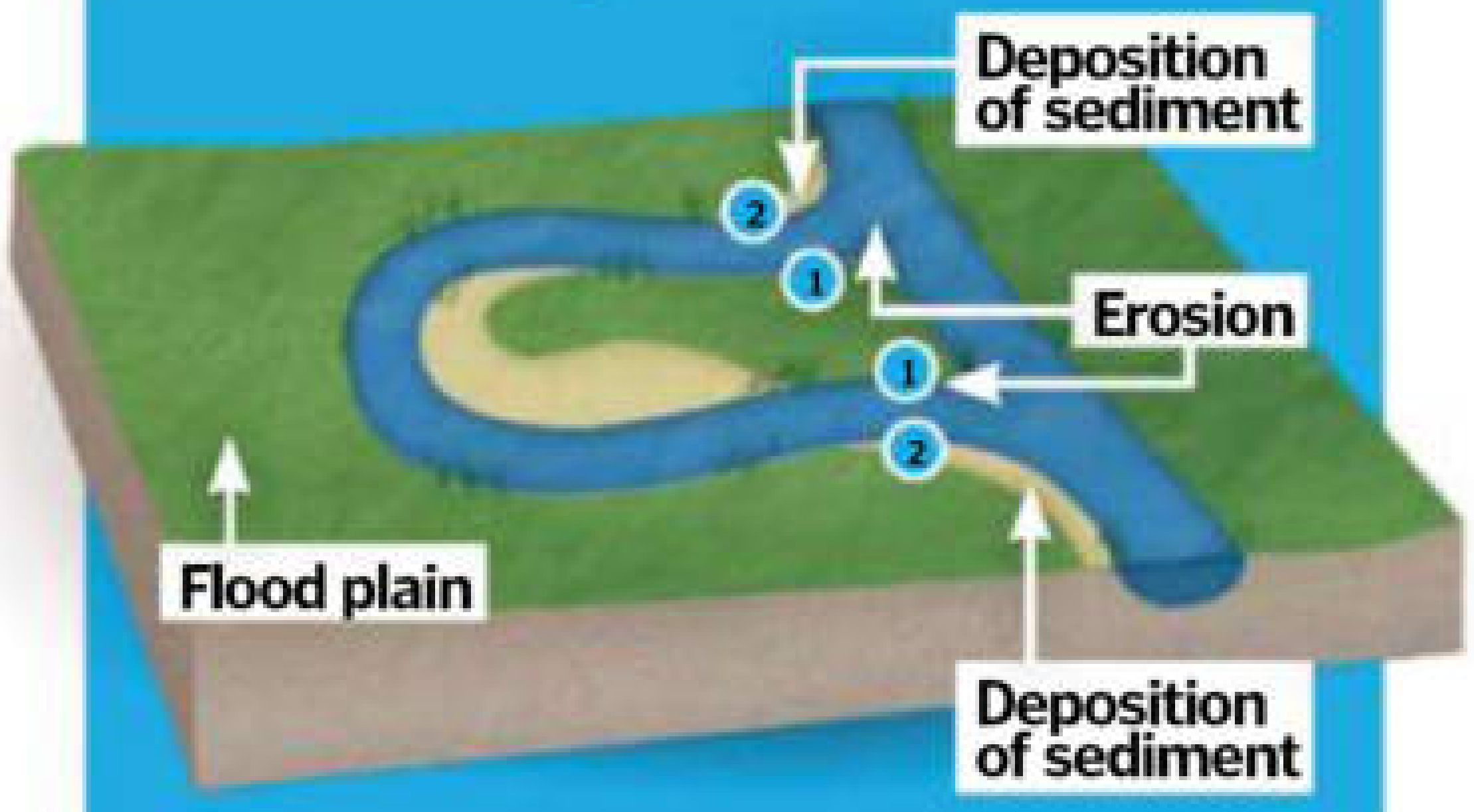
Oxbow lakes

Oxbow lakes are crescent- or horseshoe-shaped lakes situated at the side of a flowing river. They are formed from river meanders and are the result of lateral erosion cutting into the bends of the river's course where the river is flowing at its fastest. This eventually leads to the two bends joining together and altering the river's course. Deposition also plays a role as sediment builds up on the outside of the bend where the river flow is much slower. As the river breaks through and the bends join, the sediment builds up to cut off the meander and an oxbow lake is formed.



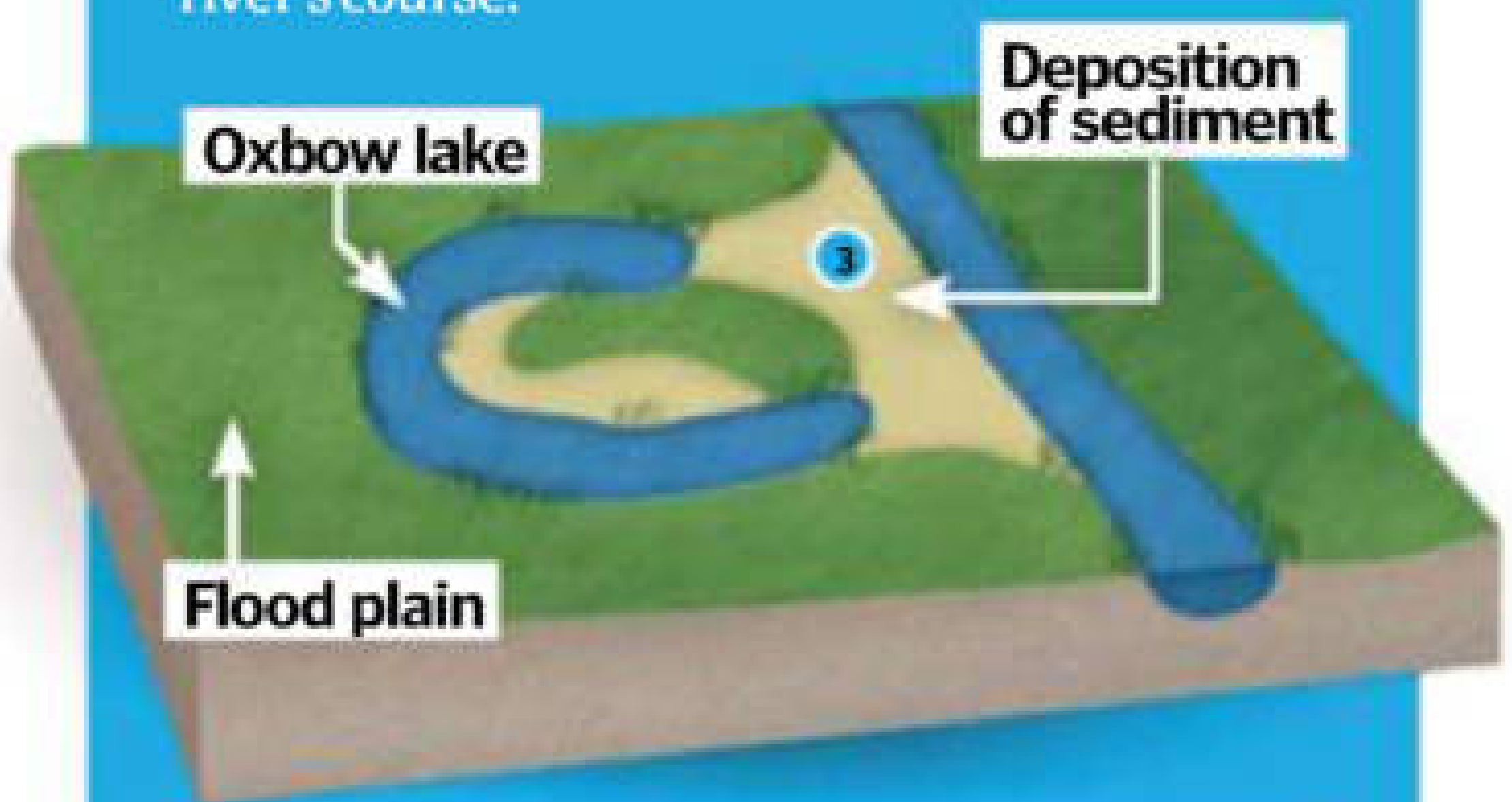
Stage one

As the water flows around the meander it flows fastest at points 1, leading to the materials carried by the river crashing into (and therefore eroding) the bends.



Stage two

The river flows slowest at points 2, which leads to deposition of sediment. The continuous erosion at points 1 has led to breakthrough, where the curves of the meander have joined together, changing the flow of the river's course.



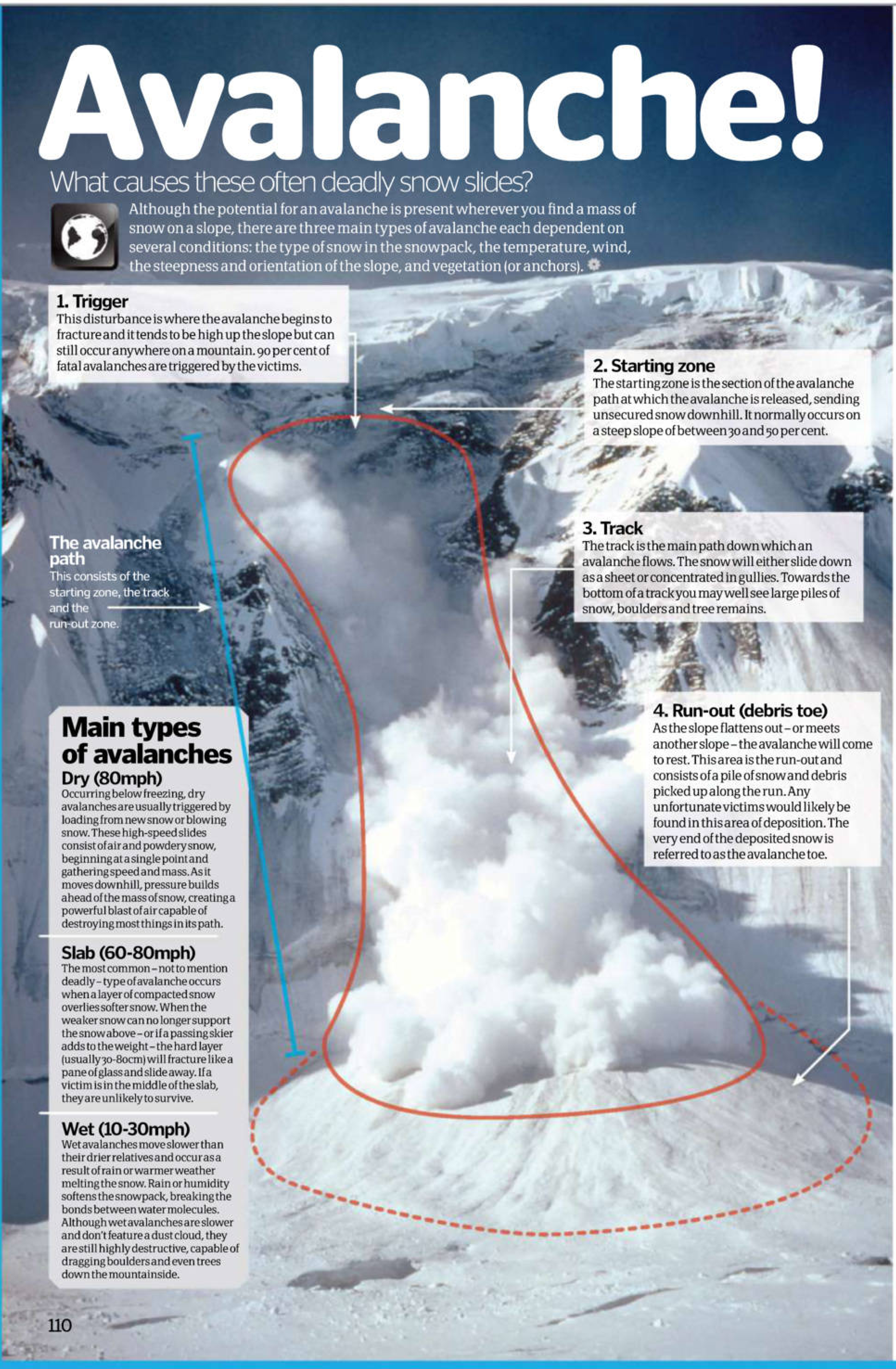
Stage three

More deposition at point 3 has led to a crescent-shaped lake being completely separated from the river. This lake is known as an oxbow lake and in time will become a wetland, followed by a meadow where trees and plants will develop.

Avalanche!

What causes these often deadly snow slides?

Although the potential for an avalanche is present wherever you find a mass of snow on a slope, there are three main types of avalanche each dependent on several conditions: the type of snow in the snowpack, the temperature, wind, the steepness and orientation of the slope, and vegetation (or anchors).



1. Trigger

This disturbance is where the avalanche begins to fracture and it tends to be high up the slope but can still occur anywhere on a mountain. 90 per cent of fatal avalanches are triggered by the victims.

2. Starting zone

The starting zone is the section of the avalanche path at which the avalanche is released, sending unsecured snow downhill. It normally occurs on a steep slope of between 30 and 50 per cent.

3. Track

The track is the main path down which an avalanche flows. The snow will either slide down as a sheet or concentrated in gullies. Towards the bottom of a track you may well see large piles of snow, boulders and tree remains.

4. Run-out (debris toe)

As the slope flattens out – or meets another slope – the avalanche will come to rest. This area is the run-out and consists of a pile of snow and debris picked up along the run. Any unfortunate victims would likely be found in this area of deposition. The very end of the deposited snow is referred to as the avalanche toe.

The avalanche path

This consists of the starting zone, the track and the run-out zone.

Main types of avalanches

Dry (80mph)

Occurring below freezing, dry avalanches are usually triggered by loading from new snow or blowing snow. These high-speed slides consist of air and powdery snow, beginning at a single point and gathering speed and mass. As it moves downhill, pressure builds ahead of the mass of snow, creating a powerful blast of air capable of destroying most things in its path.

Slab (60-80mph)

The most common – not to mention deadly – type of avalanche occurs when a layer of compacted snow overlies softer snow. When the weaker snow can no longer support the snow above – or if a passing skier adds to the weight – the hard layer (usually 30-80cm) will fracture like a pane of glass and slide away. If a victim is in the middle of the slab, they are unlikely to survive.

Wet (10-30mph)

Wet avalanches move slower than their drier relatives and occur as a result of rain or warmer weather melting the snow. Rain or humidity softens the snowpack, breaking the bonds between water molecules. Although wet avalanches are slower and don't feature a dust cloud, they are still highly destructive, capable of dragging boulders and even trees down the mountainside.

Interview

We spoke to **Cam Campbell**, public avalanche forecaster for the Canadian Avalanche Centre, to find out more

What are the most common avalanche triggers?

Cam Campbell: The most common triggers for all types of avalanches are natural; [including] loading from new snow, rain or blowing snow, rapid warming of the snowpack from an increase in air temperature or intense solar radiation, falling cornices, or other natural snowpack stressors. [...] Most fatal avalanches are human-triggered by the victim or someone in their party.

How and why are avalanches sometimes triggered intentionally?

CC: [Avalanches are triggered intentionally] to reduce the threat of future uncontrolled avalanches. Any time an avalanche is intentionally triggered, strict procedures, such as access closures and spotters are in place to ensure nobody will be adversely affected. Ski resorts or commercial backcountry operations often stabilise slopes by triggering avalanches before opening to the public. Intentional triggering can be achieved safely through remote-controlled explosives well away from the avalanche path, or hand- or helicopter-deployed explosives above the path.

Survival tips

The top ten survival tips for mountaineers and skiers

- ✓ Take avalanche safety course
- ✓ Read avalanche bulletin
- ✓ Choose route or terrain appropriate for conditions
- ✓ Carry and practise using safety gear (transceiver, shovel and probe)
- ✓ Never travel alone
- ✓ Avoid common trigger points such as convexities, thin areas, or below protruding rocks or trees
- ✓ Travel on avalanche prone slopes one person at a time and spot from safe locations
- ✓ If caught do everything in your power to escape the flowing mass
- ✓ If burial is imminent, create an air pocket in front of your face with hands and arms
- ✓ If buried, remain calm and await rescue

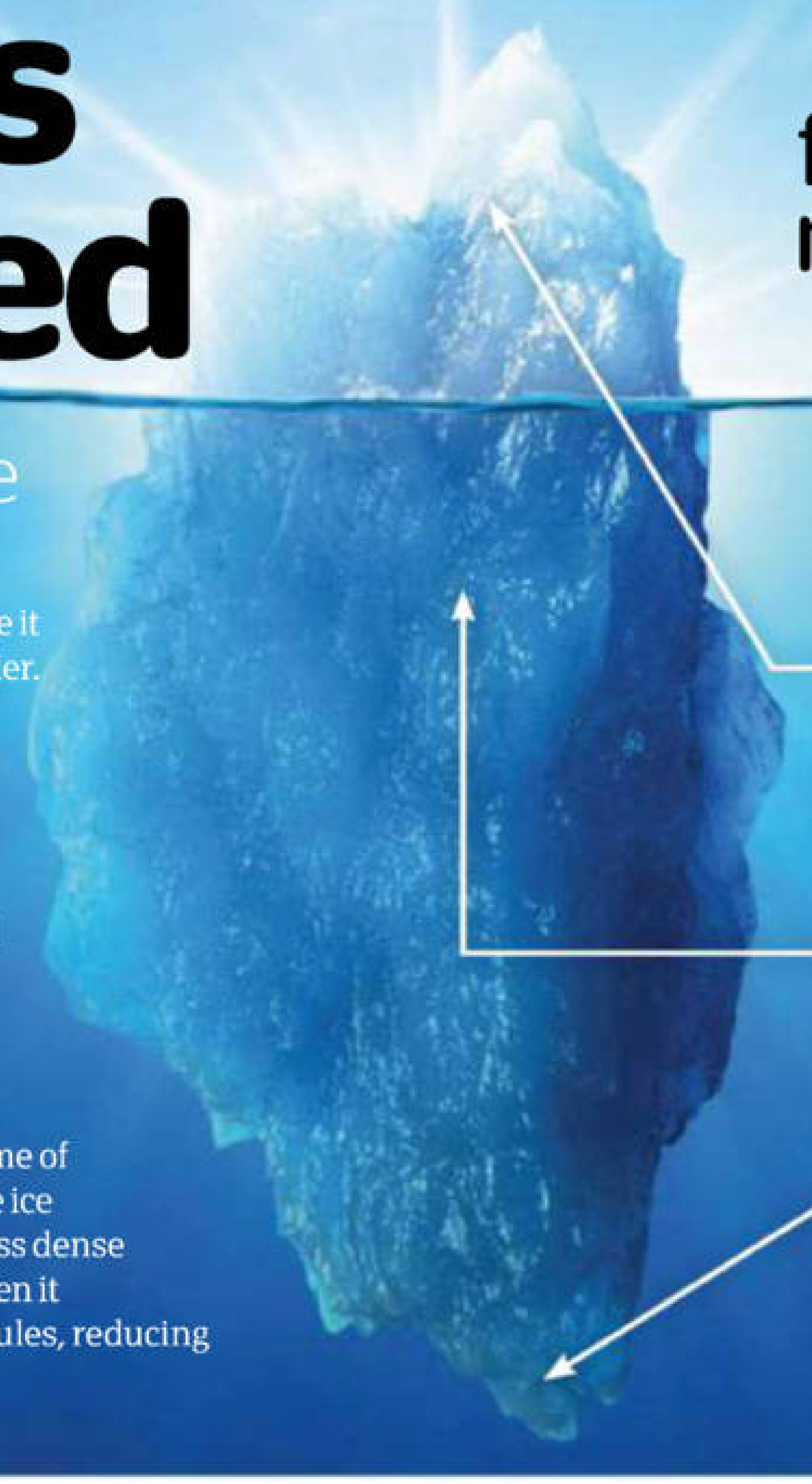
© Science Photo Library

Icebergs explained

Where do these floating ice masses come from?

An iceberg only becomes an iceberg once it has broken away from the front of a glacier. When glacial ice arrives at the coast, it carries on moving over the water and becomes an ice shelf. The movement of the tides, together with the sheer weight of the ice shelf, causes fissures that weaken the ice, causing bits to break off and float away. This 'breaking off' is called calving and the 'bits' are known as icebergs.

You only see a fraction of the iceberg above sea level, but it doesn't sink thanks to buoyancy. The upward force of buoyancy acting upon an object floating in a liquid is equal to the weight of the volume of liquid that is displaced by the object. The reason the ice isn't immersed is that – unlike other solids – ice is less dense than the liquid form it once had. When water is frozen it crystalises, meaning there's air between the molecules, reducing its density and enabling it to float.



Above the line
Usually 1/5th of an iceberg is above the waterline. That part consists of snow, which is not very compact.

Below the line
The ice in the cold core is very compact (and therefore relatively heavy) and keeps 4/5th of the iceberg under water.

Freshwater
Glacial ice (and so icebergs) is made from snowfall, which is freshwater. That's why icebergs are made from freshwater, not saltwater.

> "When water is frozen it crystalises, reducing its density so it can float"

© Thinkstock

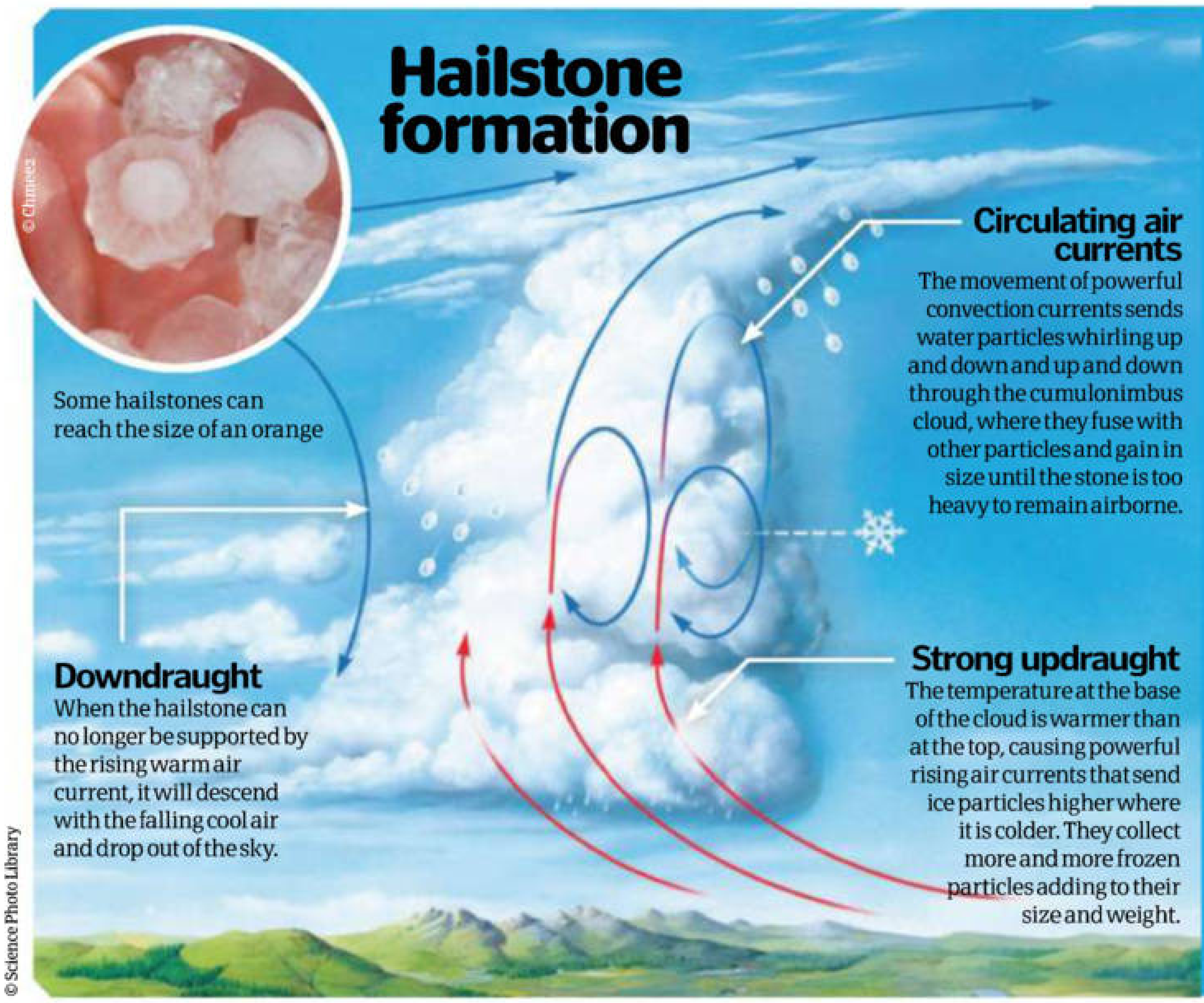
Hailstones

The balls of ice that fall to the ground, ruining crops, denting cars and smashing greenhouses

Hailstones form in the upper parts of freezing storm clouds – the cumulonimbus kind – which feature very powerful convection air currents that stretch up to ten kilometres into the atmosphere. They consist of many layers of either clear, hard ice, or softer milky snow, formed under different conditions, which can be seen if you slice a hailstone in half. Most hailstones are about the size of a marble, but can occasionally be as large as oranges.

Water droplets form inside storm clouds and are drawn upwards by strong rising air currents where they turn into ice. On its journey up, an ice particle will bump into even colder water particles – they then stick together and gain in size and weight, creating another layer of ice. As the hailstone grows heavier, it falls back down through the cloud, colliding with yet more ice particles on their way up.

The hailstone can circulate around the cloud many times, gaining more and more layers of ice, until it becomes too heavy for the air current to support. At this point it will drop out of the cloud completely, falling to earth.



Hailstone formation

Some hailstones can reach the size of an orange

Circulating air currents
The movement of powerful convection currents sends water particles whirling up and down and up and down through the cumulonimbus cloud, where they fuse with other particles and gain in size until the stone is too heavy to remain airborne.

Strong updraught
The temperature at the base of the cloud is warmer than at the top, causing powerful rising air currents that send ice particles higher where it is colder. They collect more and more frozen particles adding to their size and weight.

Downdraught
When the hailstone can no longer be supported by the rising warm air current, it will descend with the falling cool air and drop out of the sky.

© Chmee2

© Science Photo Library

The water cycle

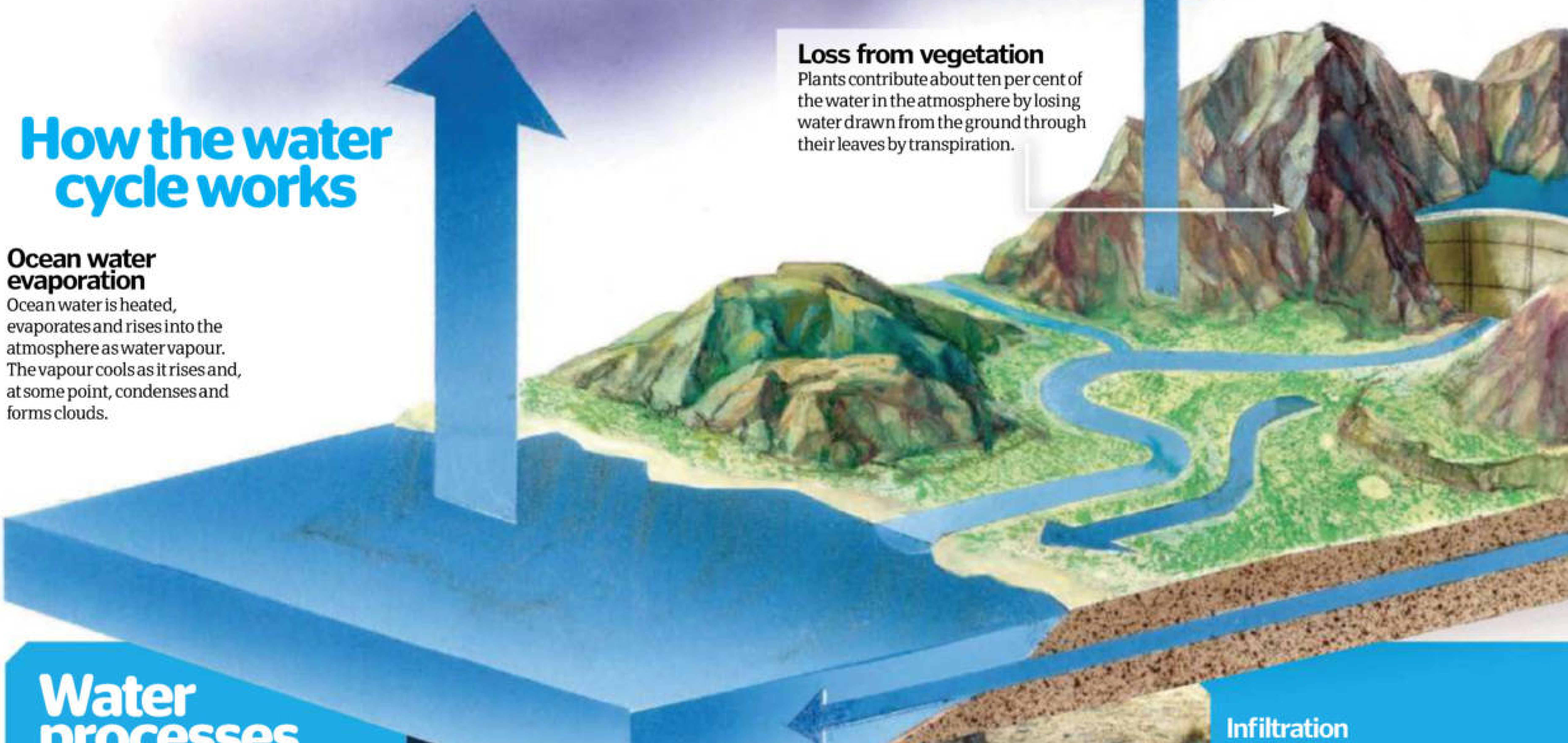
Rain falling today has spent billions of years travelling between Earth's clouds, oceans and ice

The water – or hydrological – cycle is the Earth's water recycling system. Since water rarely escapes the planet or arrives from space, the water cycle keeps rivers relentlessly flowing into the oceans and the atmosphere supplied with clouds and rain. Without it, life simply couldn't exist.

The water cycle circulates water between the oceans and atmosphere, sometimes via the land. When ocean water is heated, it turns into water vapour, which rises into the atmosphere and is carried by winds. The vapour cools at some point and forms clouds. Around 78 per cent of the rain, snow and other forms of precipitation falling from these clouds goes straight back into the ocean. The rest falls over the Earth's continents and islands.

Some of this water runs into rivers and lakes and is carried back to the sea. Water also seeps back to the oceans through deep soil and rocks, becoming the Earth's groundwater. Water falling as snow over the polar ice sheets can be buried, sometimes for millions of years, until it reaches the sea via slow-moving glaciers. Water that stays in shallow soil can be lifted back into the atmosphere when it warms. Alternatively, plants may suck up soil water through their roots and return it to the atmosphere through their leaves. When animals eat plants, they take the water into their bodies and expel it into the air in their breath.

Humans are increasingly altering the water cycle on land by building cities and flood controls, and capturing water for drinking, as well as agriculture and industries.



How the water cycle works

Ocean water evaporation
Ocean water is heated, evaporates and rises into the atmosphere as water vapour. The vapour cools as it rises and, at some point, condenses and forms clouds.

Loss from vegetation
Plants contribute about ten per cent of the water in the atmosphere by losing water drawn from the ground through their leaves by transpiration.

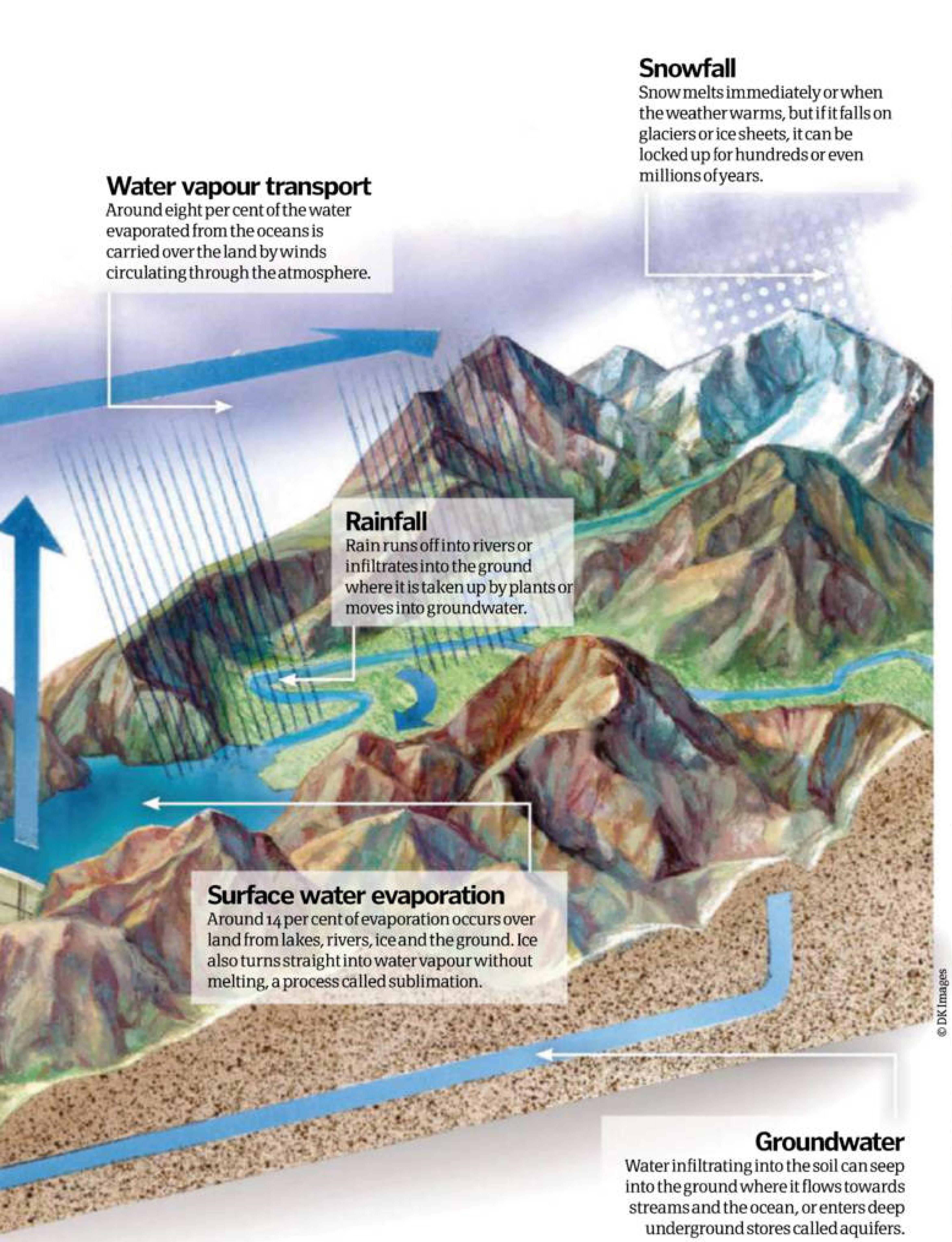
Water processes explained

Condensation

When you breathe on a cold window and it fogs up, you're seeing condensation in action. It's the process by which water vapour in the air turns back into liquid water when it cools down. Atmospheric water vapour condenses on salt, smoke and dust particles to form clouds.

Infiltration

Infiltration is where water seeps into the ground rather than running across it. Once in the ground, the water stays in shallow soil layers or moves deeper to form groundwater. Dry, loose soils on flat ground will absorb more water than steeply sloping hard surfaces or already wet soil.



Snowfall
Snow melts immediately or when the weather warms, but if it falls on glaciers or ice sheets, it can be locked up for hundreds or even millions of years.

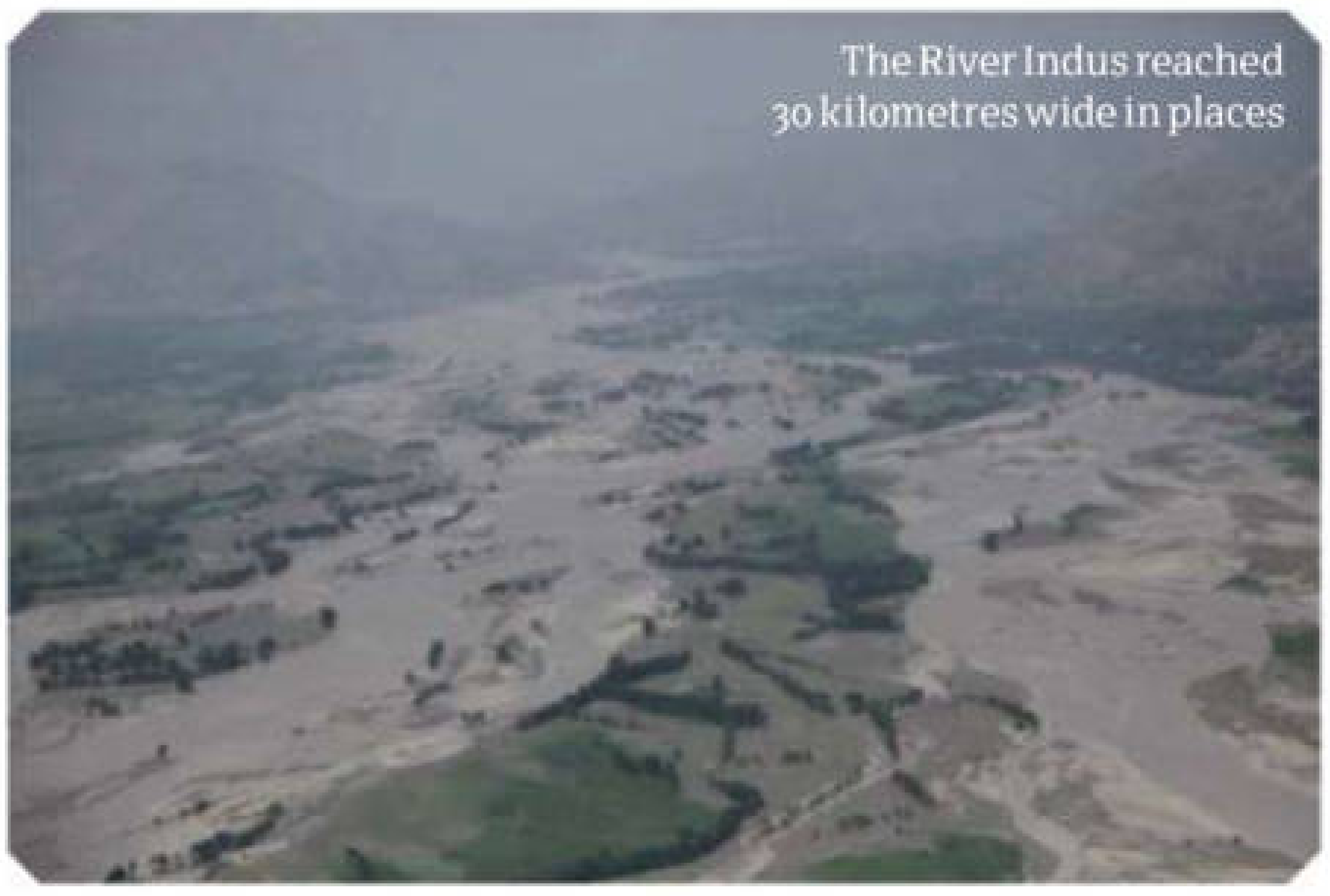
Water vapour transport
Around eight per cent of the water evaporated from the oceans is carried over the land by winds circulating through the atmosphere.

Rainfall
Rain runs off into rivers or infiltrates into the ground where it is taken up by plants or moves into groundwater.

Surface water evaporation
Around 14 per cent of evaporation occurs over land from lakes, rivers, ice and the ground. Ice also turns straight into water vapour without melting, a process called sublimation.

Groundwater
Water infiltrating into the soil can seep into the ground where it flows towards streams and the ocean, or enters deep underground stores called aquifers.

© DK Images



The River Indus reached 30 kilometres wide in places

When the water cycle lets us down

Floods affect tens of thousands of people each year, as is evident from 2010's devastating monsoon flooding across Pakistan. The flood, which affected some 20 million people, was the result of the heaviest monsoon rains in the area for generations. On 8 August 2010 the River Indus burst its banks, sweeping away entire communities. While it's normal for Pakistan to receive half its annual rainfall (250-500mm) during the monsoon months of July and August, the country was reportedly bombarded with 300mm on 29 July alone. The Met Office suggests several possible reasons for the unusually heavy rains, including changes to upper atmosphere airflow, active monsoon systems, and La Niña (El Niño in reverse).

Serious floods, like those seen in Pakistan during July and August 2010, can cause catastrophic destruction

Runoff

Water flowing down tarmac roads into curb-side drains after a storm is an example of the process of runoff. Rain that doesn't evaporate or infiltrate into soil or rock also flows down small channels as runoff. The channels merge into streams that, eventually, join rivers flowing downhill to the sea.

Evaporation

Wet clothes hung outside dry by evaporation, the process by which liquid water turns into vapour when heat energy breaks bonds between its water molecules. Soaking a T-shirt keeps you cool on a hot day because since evaporation uses up heat energy from the air, it reduces nearby temperatures.

Precipitation

Precipitation is a catch-all term for water falling from clouds to the earth. It covers rain, snow, hail and so on. Precipitation happens when water vapour condenses on airborne particles as droplets. These grow bigger by, for example, collisions until they become so heavy they fall to the ground.

Transpiration

Plants – like humans – breathe out water vapour, a process called transpiration. During transpiration, water drawn into a plant's roots is carried to the leaves where it evaporates. How much plants transpire varies depending on air temperature, humidity and incoming sunlight. Higher temperatures and stronger sunlight mean more transpiration.

The Earth's atmosphere

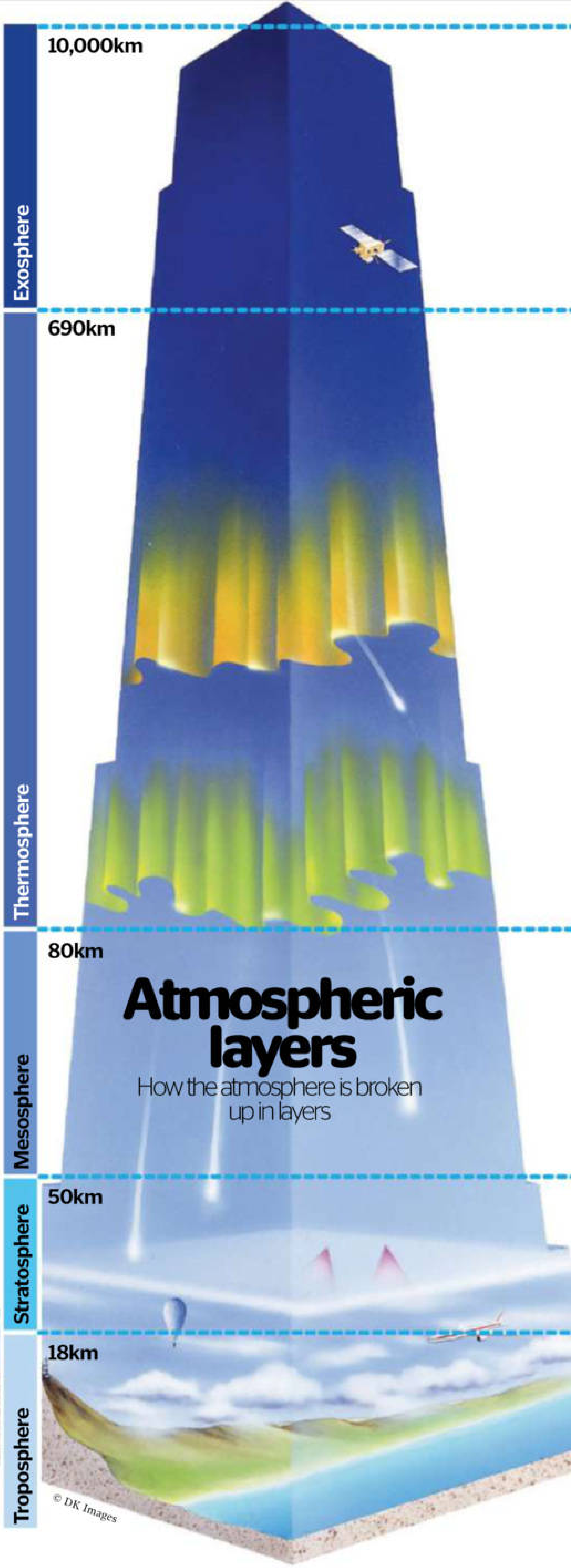
It's all around us, but how much do we know about our atmosphere?

Our atmosphere (made up of 78 per cent nitrogen and 21 per cent oxygen, with other gases making up the last per cent) is held in place by gravity and consists of a number of different layers that work together to protect us from solar radiation and to keep consistent temperatures. The atmosphere gets thinner with altitude, with 80 per cent of its mass in the first layer closest to the Earth's surface. There are five main layers that make up the atmosphere. The troposphere is the first layer (and is where our weather occurs), followed by the stratosphere, mesosphere, thermosphere and exosphere. There is no definite boundary between where the atmosphere ends and outer space begins, though the Kàrmàn line at 100km above sea level is often regarded as a the boundary.

There are other layers that exist alongside the five main layers. The lowest of these is the 'planetary boundary', which is within the troposphere and closest to the Earth's surface and its depth can vary widely between 100m to 3,000m as it is directly affected by conditions on the surface. The ozone layer is the one that most of us will be familiar with and this is contained within the stratosphere, in its lower portion. Around 90 per cent of the ozone in the atmosphere lies here. The ionosphere is what causes auroras, such as the northern lights, as it is ionised by solar radiation and stretches from 50 to 1,000km, overlapping the exosphere and thermosphere.

Finally, the homosphere and the heterosphere run from the Earth's surface to around 80km and from 80km upwards respectively. They are so-named because of the way the gases within them are mixed. The heterosphere has a chemical composition that changes with height, whereas the homosphere's make-up remains more constant. The five main layers are based on the thermal structure of the atmosphere, whereas the additional layers mentioned here are classified according to composition.

The northern lights are caused partly by the atmosphere



Atmospheric layers

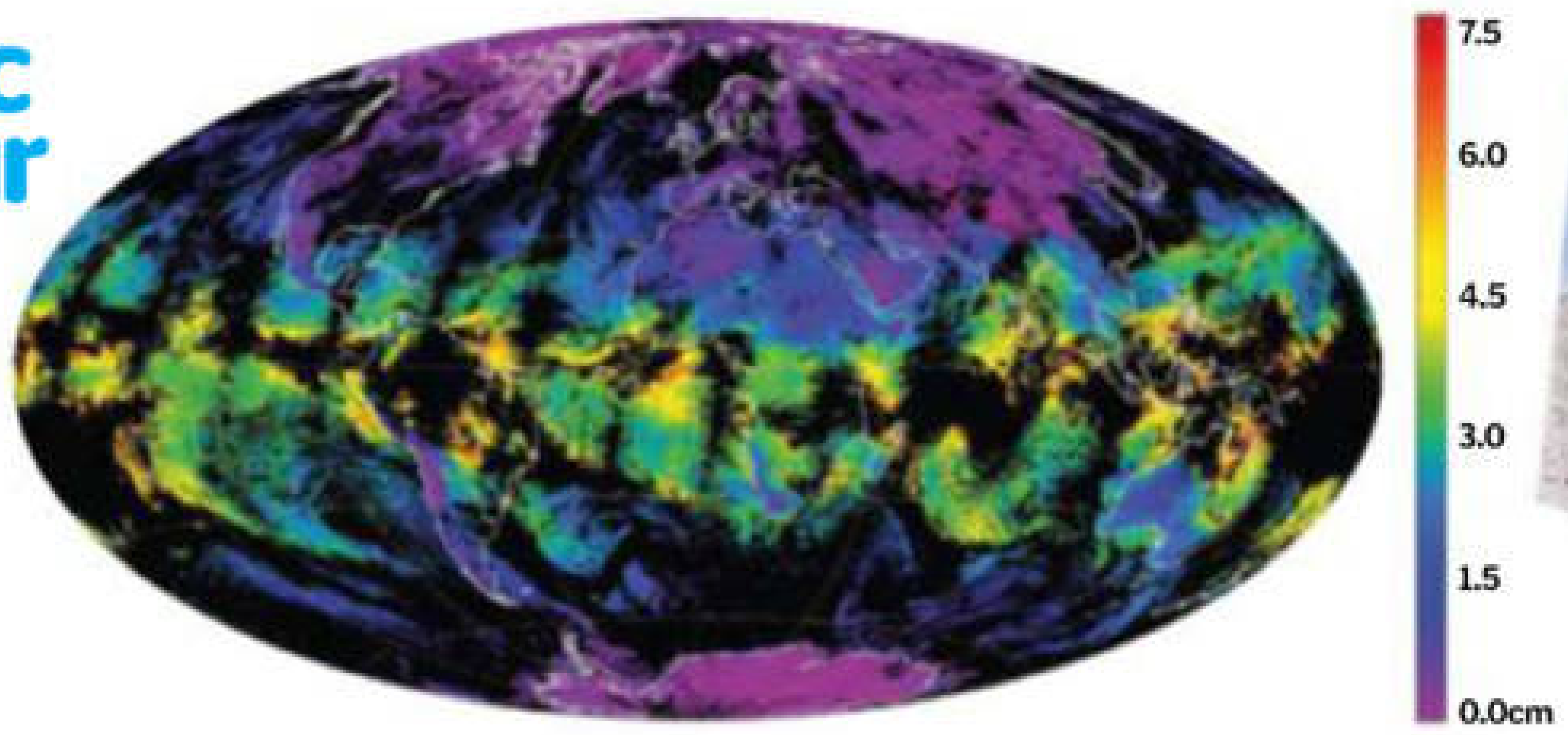
How the atmosphere is broken up in layers

© DK Images

Atmospheric water vapour

Moisture in the air

The gaseous water vapour in our atmosphere is responsible for our rain, snow, hail, fog, and clouds. If the vapour was to fall evenly over the planet as precipitation, each year 25mm of water will have fallen.



5. Exosphere
The final layer where particles are widely spaced and can travel hundreds of kilometres before colliding with another particle. The makeup of this layer is mainly hydrogen and helium.

© NASA

4. Thermosphere
Temperatures start to increase with height. This is also the layer in which the International Space Station orbits, between 320 and 380km, and shuttles fly into. It extends up to the base of the exosphere, called the exobase.

This rock made it through the mesosphere

3. Mesosphere
Extends from the stratopause (again, the layer boundary) to a height of 80-85km and is notably the layer in which meteors burn up when entering the atmosphere. Temperatures decrease with height, and in the mesopause is the coldest place on Earth (around -100°C).

2. Stratosphere
Starts from the tropopause (the boundary between the first two layers) up to around 51km, with temperatures increasing with height. This is where you'll find things like weather balloons.

1. Troposphere
The first layer of atmosphere, starting at the Earth's surface and extending to between 7km and 17km. It is heated by a transfer of energy from the Earth's surface, so it gets cooler as it goes higher.

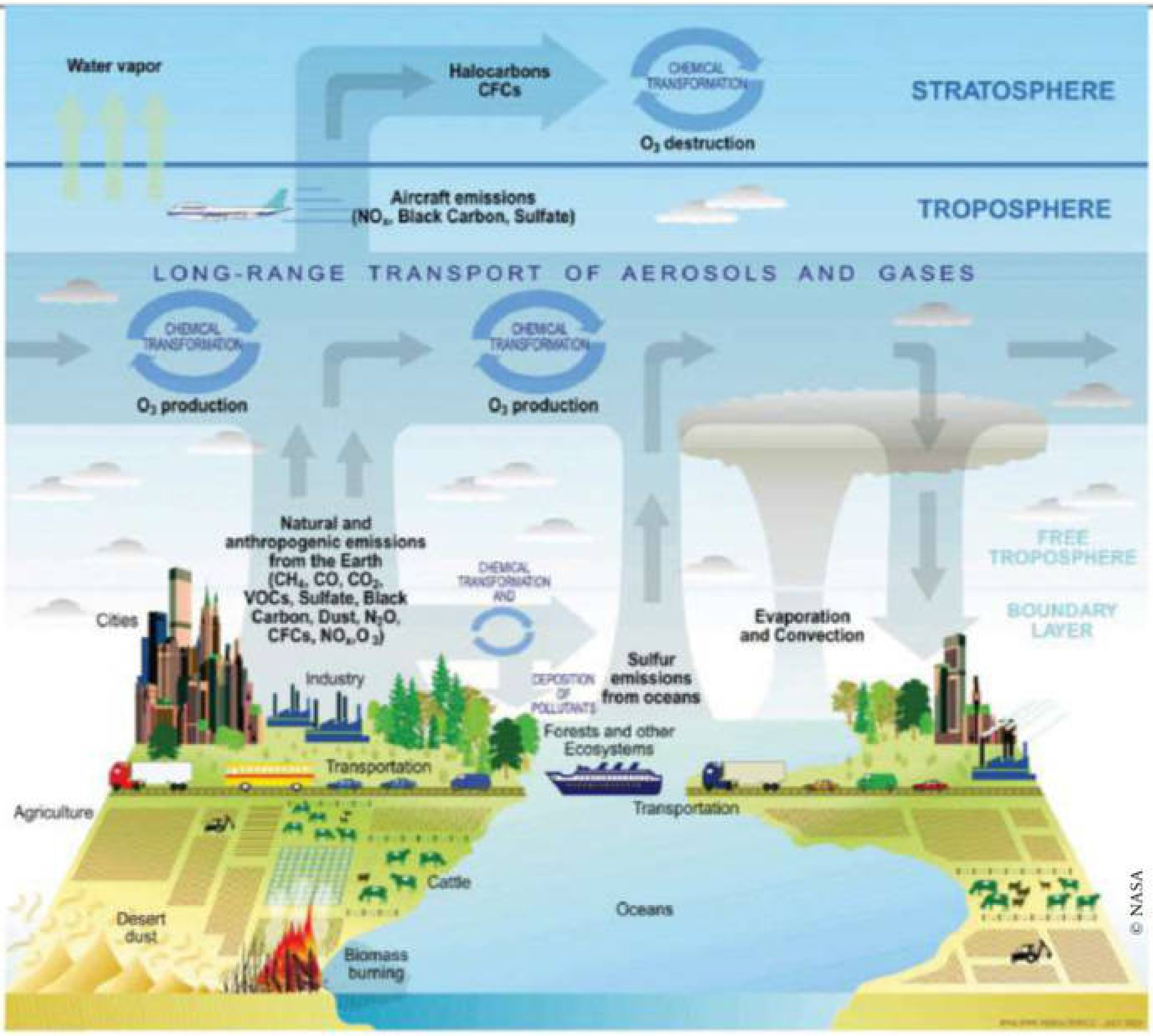
Pollution in the air

The effects of pollution include smog, acid rain, the greenhouse effect, and holes in the ozone layer. Each problem has implications for both our own health and the environment around us.

The carbon dioxide gas produced when fuel is burned may contribute to the greenhouse effect. Plants can convert CO_2 back to oxygen, but the human production of CO_2 currently exceeds the amount the plants can convert back.

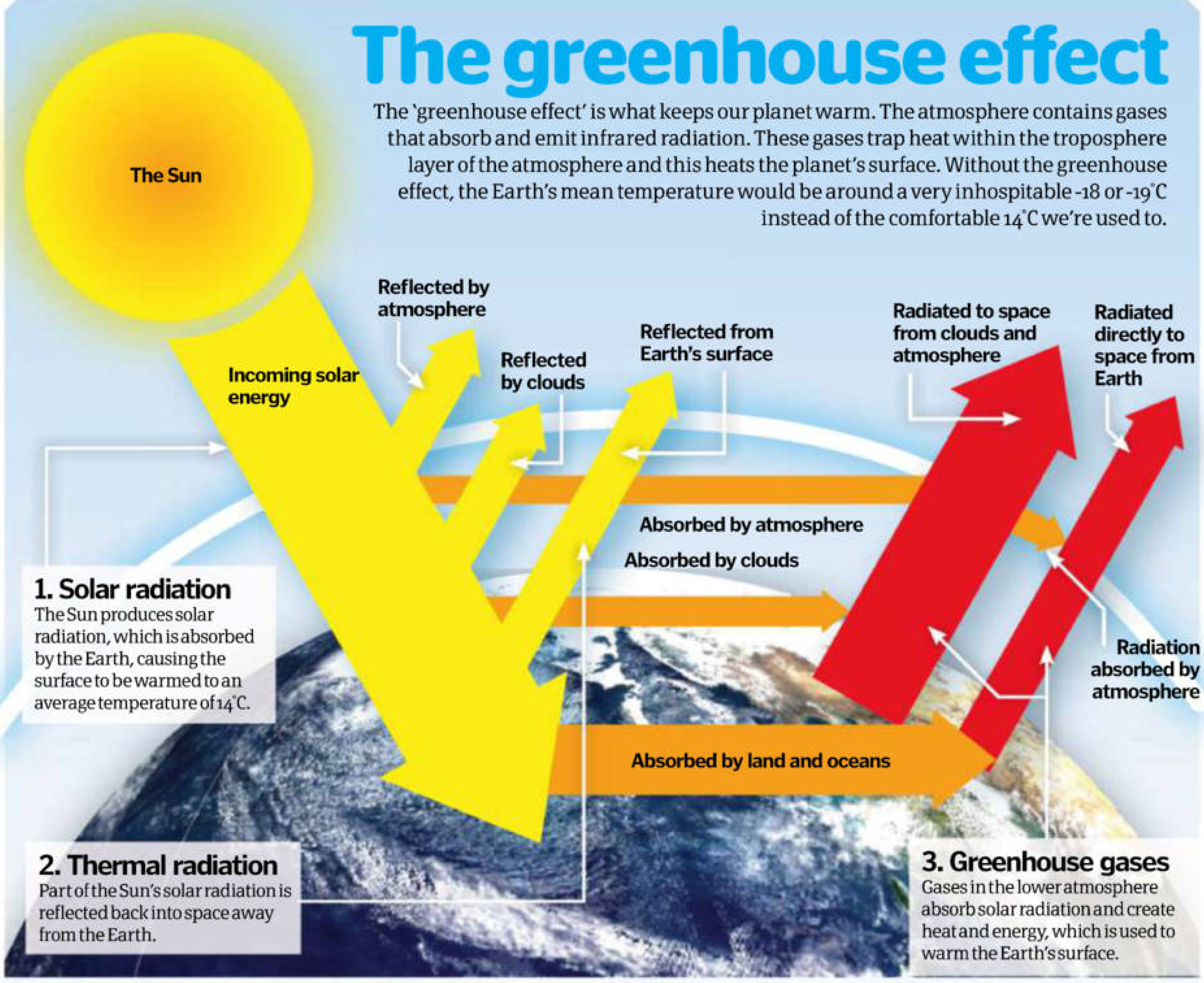
Rife in cities, smog is the result of smoke, fog, and chemical fumes caused when different pollutants combine.

Acid rain occurs when a pollutant, such as sulfuric acid combines with droplets of water in the precipitation and becomes acidified.


Water vapor
Halocarbons CFCs
CHEMICAL TRANSFORMATION
O₃ destruction
STRATOSPHERE
Aircraft emissions (NOₓ, Black Carbon, Sulfate)
TROPOSPHERE
LONG-RANGE TRANSPORT OF AEROSOLS AND GASES
CHEMICAL TRANSFORMATION
O₃ production
CHEMICAL TRANSFORMATION
O₃ production
Natural and anthropogenic emissions from the Earth (CH₄, CO, CO₂, VOCs, Sulfate, Black Carbon, Dust, N₂O, CFCs, NOₓ, O₃)
CHEMICAL TRANSFORMATION AND
DEPOSITION OF POLLUTANTS
Sulfur emissions from oceans
Evaporation and Convection
FREE TROPOSPHERE
BOUNDARY LAYER
Cities
Industry
Forests and other Ecosystems
Transportation
Transportation
Agriculture
Cattle
Oceans
Desert dust
Biomass burning
© NASA

The greenhouse effect

The 'greenhouse effect' is what keeps our planet warm. The atmosphere contains gases that absorb and emit infrared radiation. These gases trap heat within the troposphere layer of the atmosphere and this heats the planet's surface. Without the greenhouse effect, the Earth's mean temperature would be around a very inhospitable -18 or -19°C instead of the comfortable 14°C we're used to.


The Sun
Incoming solar energy
Reflected by atmosphere
Reflected by clouds
Reflected from Earth's surface
Radiated to space from clouds and atmosphere
Radiated directly to space from Earth
Absorbed by atmosphere
Absorbed by clouds
Radiation absorbed by atmosphere
Absorbed by land and oceans

1. Solar radiation
The Sun produces solar radiation, which is absorbed by the Earth, causing the surface to be warmed to an average temperature of 14°C.

2. Thermal radiation
Part of the Sun's solar radiation is reflected back into space away from the Earth.

3. Greenhouse gases
Gases in the lower atmosphere absorb solar radiation and create heat and energy, which is used to warm the Earth's surface.

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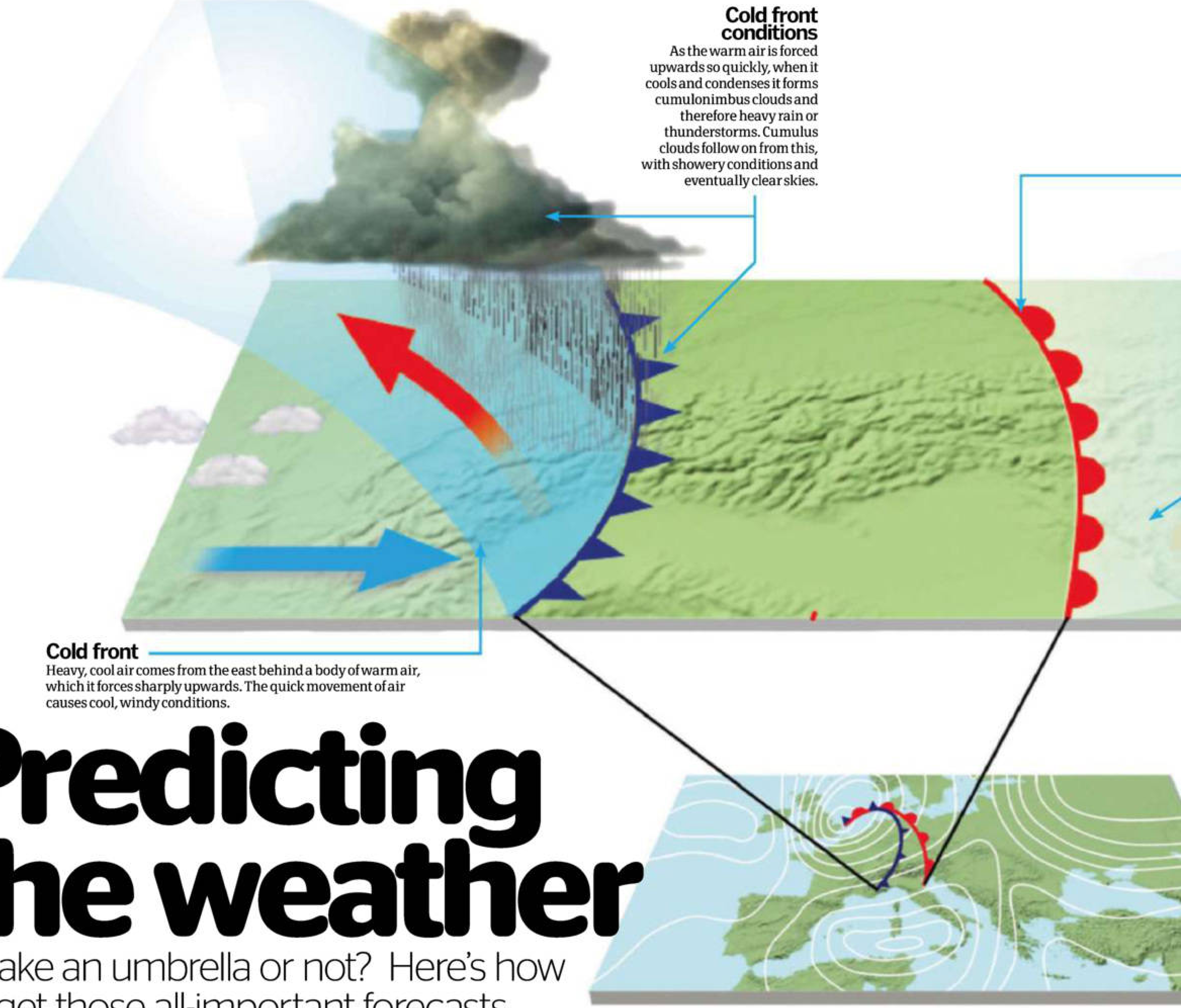


Cold front conditions
As the warm air is forced upwards so quickly, when it cools and condenses it forms cumulonimbus clouds and therefore heavy rain or thunderstorms. Cumulus clouds follow on from this, with showery conditions and eventually clear skies.

Cold front
Heavy, cool air comes from the east behind a body of warm air, which it forces sharply upwards. The quick movement of air causes cool, windy conditions.

Predicting the weather

To take an umbrella or not? Here's how we get those all-important forecasts...

The simple fact of the matter is that weather is unpredictable. So how is it that we can gather information and make predictions about what conditions on Earth will be like?

Most weather phenomena occur as a result of the movement of warm and cold air masses. The border between these bodies of air are known as 'fronts', and it's here that the most exciting weather, including precipitation and wind, occurs.

As a body of air passes across different types of terrain – such as over the oceans, low-lying areas or even mountainous regions – air temperature and moisture levels can change dramatically. When two air masses at different temperatures meet, the less dense, warmer of the two masses rises up and over the colder. Rising warm air creates an area of low pressure (a depression), which is associated with unsettled conditions like wind and rain.

We know how a frontal weather system will behave and which conditions it will produce down on the ground. The man who first brought the idea of frontal weather systems to the fore in the early twentieth century was a Norwegian meteorologist called Vilhelm Bjerknes. Through his constant observation of the weather conditions at frontal boundaries, he discovered that numerical calculations could be used to predict the weather. This model of weather prediction is still used today.

Since the introduction of frontal system weather forecasting, the technology to crunch the numbers involved has advanced immeasurably, enabling far more detailed analysis and prediction. In order to forecast the weather with the greatest accuracy, meteorologists require vast quantities of weather data – including temperature, precipitation, cloud coverage, wind speed and wind direction – collected from weather stations located all over the world. Readings are taken constantly and fed via computer to a central location.

Technology is essential to both gathering and processing the statistical data about the conditions down on Earth and in the upper atmosphere. The massive computational power packed inside a supercomputer, for example, is capable of predicting the path and actions of hurricanes and issuing life-saving warnings. After taking the information collected by various monitors and sensors, a supercomputer can complete billions of calculations per second to produce imagery that can reveal how the hurricane is expected to develop.

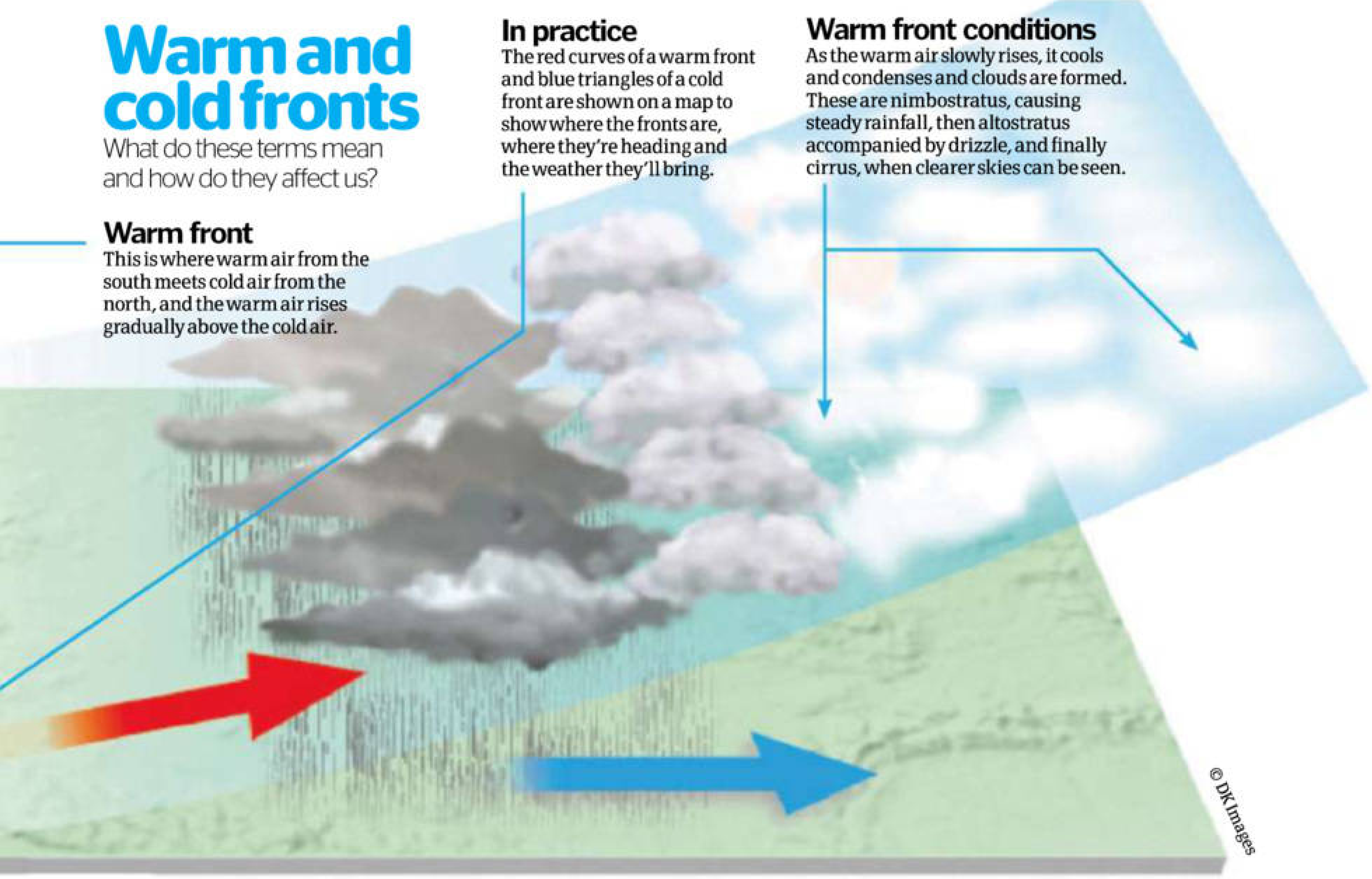
Warm and cold fronts

What do these terms mean and how do they affect us?

In practice
The red curves of a warm front and blue triangles of a cold front are shown on a map to show where the fronts are, where they're heading and the weather they'll bring.

Warm front conditions
As the warm air slowly rises, it cools and condenses and clouds are formed. These are nimbostratus, causing steady rainfall, then altostratus accompanied by drizzle, and finally cirrus, when clearer skies can be seen.

Warm front
This is where warm air from the south meets cold air from the north, and the warm air rises gradually above the cold air.



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WEATHER FORECAST MAP

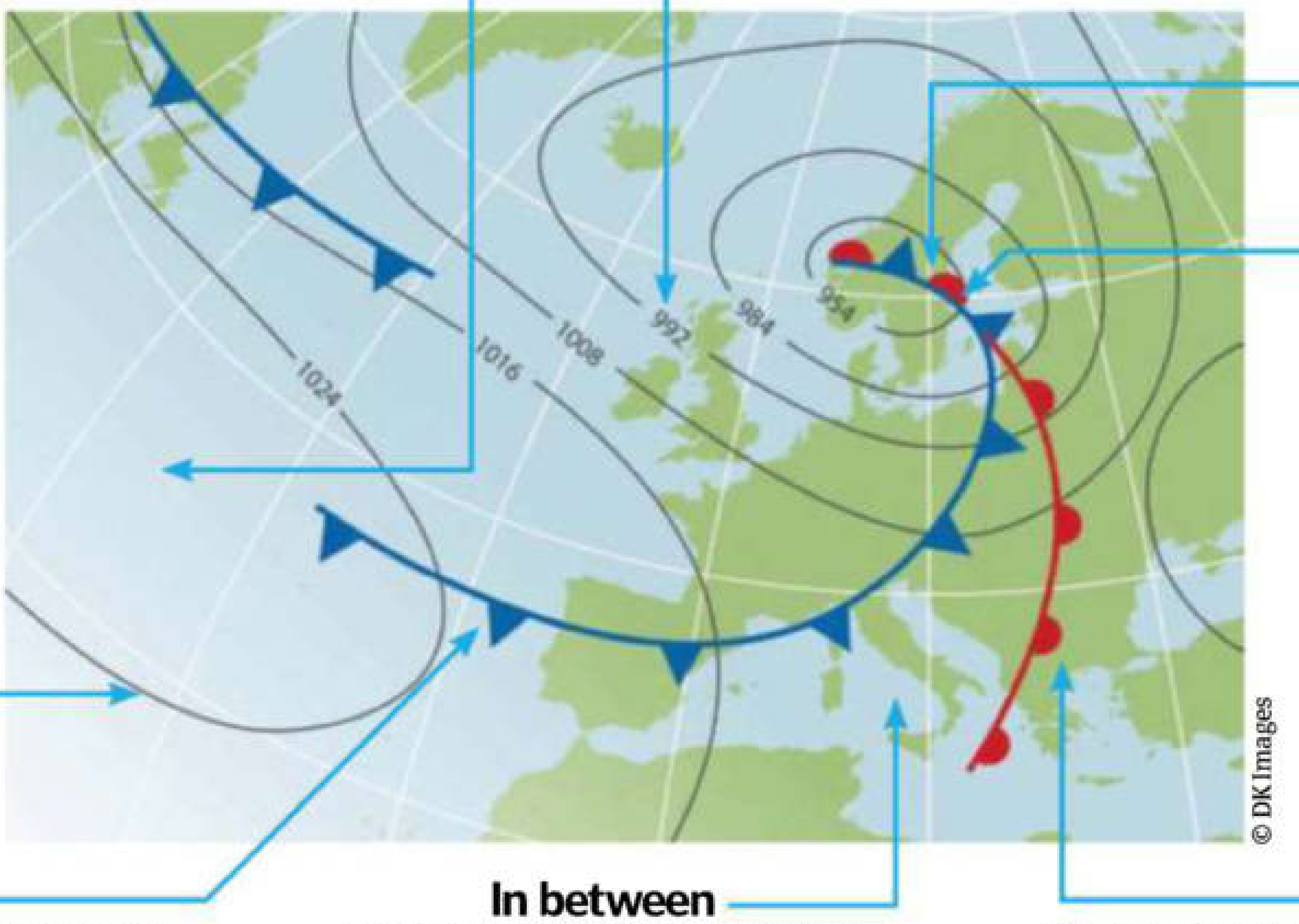
Learn what these weather-related signs and symbols mean

High pressure
Weather here will be clear and dry, due to the high pressure. If this high pressure occurs in summer weather will be warm, whereas in winter it will be cold and crisp.

Wind
The conditions at this point will be windy. This is indicated by the position of the isobars; the closer together they are the windier the conditions.

Low pressure
At the centre of these circular patterns of isobars is where systems of high or low pressure lie. Where there is low pressure conditions will be rainy and windy.

Isobars
These indicate atmospheric pressure. Areas of equal atmospheric pressure are joined together with the lines shown and the numbers indicate pressure measured in millibars. Lower numbers indicate low pressure, while higher numbers indicate high pressure.



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Occluded front
This is where one front 'catches up' with another. In this example, the cold has caught up with the warm. Occluded fronts cause the weather to change quite quickly and, in this case, become similar to that of a cold front.

Cold front
As with any cold front, the weather here will be expected to be cool with heavy rainfall and possibly even thunderstorms. This will be followed by showers.

In between
After the passing of the warm front and before the arrival of the cold front conditions should be clear and dry, but normally only for a short period.

Warm front
The warm front will cause steady rainfall, followed by drizzle, accompanied by cloudy skies. These are typical conditions caused by any warm front.

Stormy weather

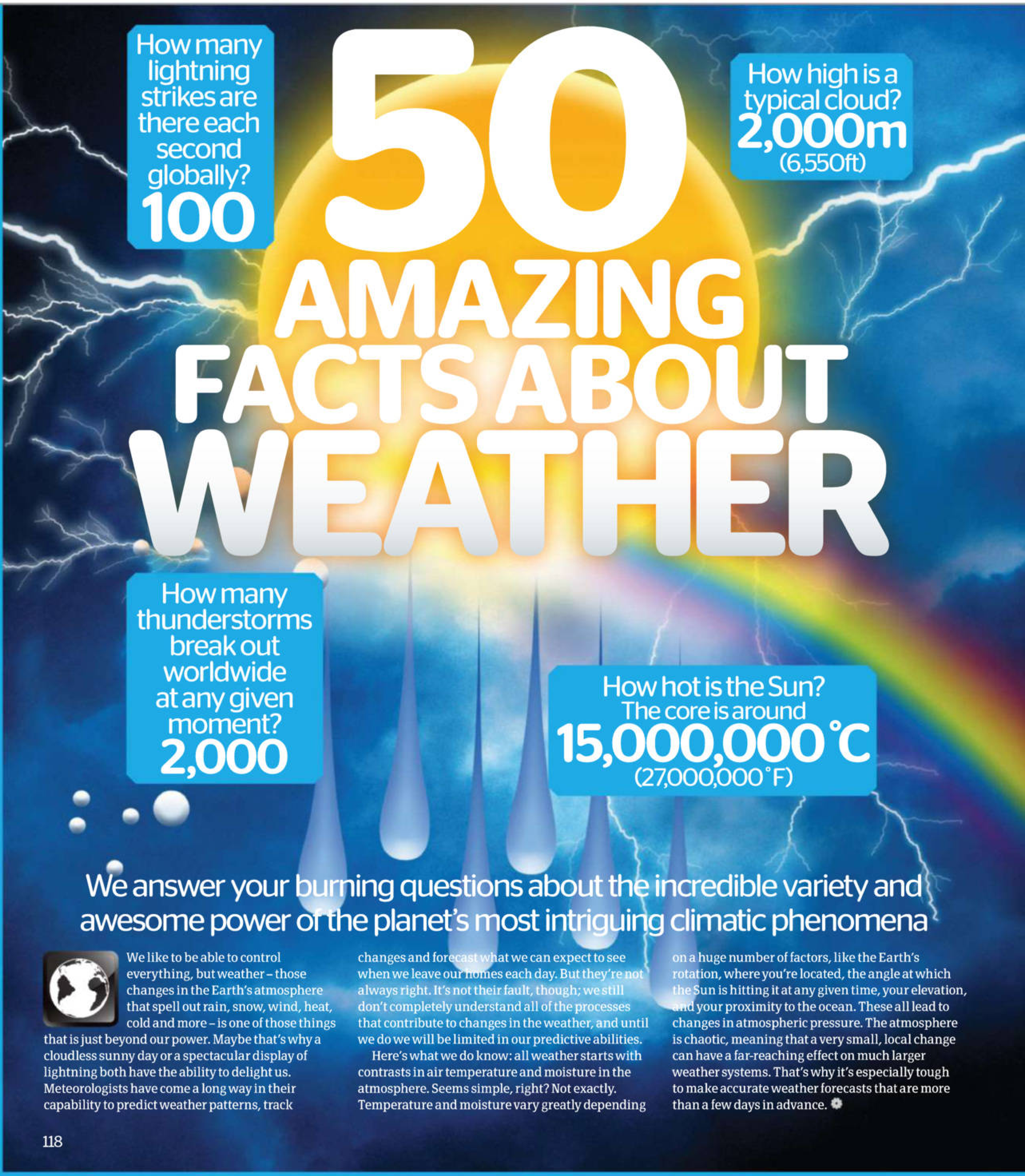
Hail
The tops of storm clouds are full of tiny ice crystals that grow heavier until they fall through the cloud. The biggest hail stone on record was 17.8cm (7in).

Lightning
A flash of lightning is a giant spark caused when the molecules in a thunder cloud collide and build up static electricity. The flash occurs when a spark jumps through a cloud, or from the cloud to the ground, or from one cloud to another.

Thunder
This is the noise produced by lightning. An increase in pressure and temperature cause the air nearby to rapidly expand, which produces the characteristic sound of a sonic boom.

Storm cloud
Your typical run-of-the-mill cloud can be hundreds of metres high. A storm cloud, however, can reach heights of over ten kilometres (that's six miles).

How many...?
A staggering 16 million thunderstorms occur each year globally.



How many lightning strikes are there each second globally?
100

50 AMAZING FACTS ABOUT WEATHER

How high is a typical cloud?
2,000m
(6,550ft)

How many thunderstorms break out worldwide at any given moment?
2,000

How hot is the Sun? The core is around
15,000,000˚C
(27,000,000˚F)

We answer your burning questions about the incredible variety and awesome power of the planet's most intriguing climatic phenomena

We like to be able to control everything, but weather – those changes in the Earth's atmosphere that spell out rain, snow, wind, heat, cold and more – is one of those things that is just beyond our power. Maybe that's why a cloudless sunny day or a spectacular display of lightning both have the ability to delight us. Meteorologists have come a long way in their capability to predict weather patterns, track changes and forecast what we can expect to see when we leave our homes each day. But they're not always right. It's not their fault, though; we still don't completely understand all of the processes that contribute to changes in the weather, and until we do we will be limited in our predictive abilities.

Here's what we do know: all weather starts with contrasts in air temperature and moisture in the atmosphere. Seems simple, right? Not exactly. Temperature and moisture vary greatly depending on a huge number of factors, like the Earth's rotation, where you're located, the angle at which the Sun is hitting it at any given time, your elevation, and your proximity to the ocean. These all lead to changes in atmospheric pressure. The atmosphere is chaotic, meaning that a very small, local change can have a far-reaching effect on much larger weather systems. That's why it's especially tough to make accurate weather forecasts that are more than a few days in advance.

Is there a way to tell how close a storm is?

Lightning and thunder always go together, because thunder is the sound that results from lightning. Lightning bolts are close to 30,000 degrees Celsius (54,000 degrees Fahrenheit), so the air in the atmosphere that they zip through becomes superheated and quickly expands. That sound of expansion is called thunder, and on average it's about 120 decibels (a chainsaw is 125, for reference). Sometimes you can see lightning but not hear the thunder, but that's only because the lightning is too far away for you to hear it. Because light travels faster than sound, you always see lightning before hearing it.

1. Start the count
When you see a flash of lightning, start counting. A stopwatch would be the most accurate way.

2. Five seconds
The rule is that for every five seconds, the storm is roughly 1.6 kilometres (one mile) away.

3. Do the maths
Stop counting after the thunder and do the maths. If the storm's close, take the necessary safety precautions.

Lightning occurs most often in hot, summer-like climates

Where are you most likely to get hit by lightning?

Generally lightning strikes occur most often during the summer. So the place where lightning strikes occur the most is a place where summer-like weather prevails year-round: Africa. Specifically, it's the village of Kifuka in the Democratic Republic of Congo. Each year, it gets more than 150 lightning strikes within one square kilometre. Roy Sullivan didn't live in Kifuka but he still managed to get struck by lightning seven separate times while working as a park ranger in the Shenandoah National Park in the USA. The state in which he lived – Virginia – does have a high incidence of lightning strikes per year, but since Sullivan spent his job outdoors in the mountains, his risk was greater due to his exposure.

What is the fastest wind ever recorded, not in a tornado?

407km/h (253mph)
Gusts recorded during Cyclone Olivia in 1996

Is it possible to stop a hurricane?

We can't control the weather… or can we? Some scientists are trying to influence the weather through cloud seeding, or altering the clouds' processes by introducing chemicals like solid carbon dioxide (aka dry ice), calcium chloride and silver iodide. It has been used to induce rainfall during times of drought as well as to prevent storms.

CAN IT REALLY RAIN ANIMALS?

Animals have fallen from the sky before, but it's not actually 'raining' them. More likely strong winds have picked up large numbers of critters from ponds or other concentrations – perhaps from tornadoes or downspouts – then moved and deposited them. Usually the animals in question are small and live in or around water for a reason.

DOES FREAK WEATHER CONFUSE WILDLIFE?

A short period of unseasonable weather isn't confusing, but a longer one can be. For example, warm weather in winter may make plants bloom too early or animals begin mating long before spring actually rolls around.

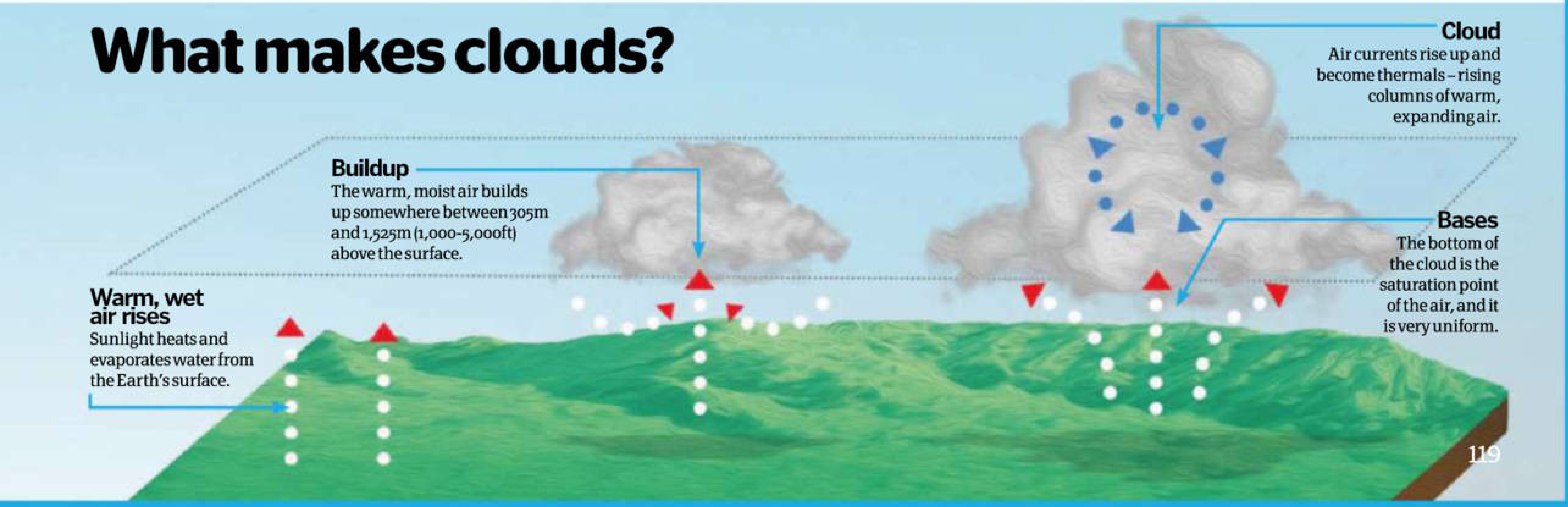
IS THE 'RED SKY AT NIGHT, SHEPHERD'S DELIGHT' SAYING TRUE?

The rest of the proverb is, 'Red sky at morning, shepherd's warning'. A red sky means you could see the red wavelength of sunlight reflecting off clouds. At sunrise, it was supposed to mean the clouds were coming towards you so rain might be on the way. If you saw these clouds at sunset, the risk had already passed. Which is 'good' or 'bad' is a matter of opinion.

WHAT ARE SNOW DOUGHNUTS?

Snow doughnuts, or rollers, are a rare natural phenomenon. If snow falls in a clump, gravity can pull it down over itself as it rolls. Normally it would collapse, but sometimes a hole forms. Wind and temperature also play key roles.

What makes clouds?



Warm, wet air rises
Sunlight heats and evaporates water from the Earth's surface.

Buildup
The warm, moist air builds up somewhere between 305m and 1,525m (1,000-5,000ft) above the surface.

Cloud
Air currents rise up and become thermals – rising columns of warm, expanding air.

Bases
The bottom of the cloud is the saturation point of the air, and it is very uniform.

What are the odds of getting hit by lightning in a lifetime?

1 in 10,000

WHAT ARE KATABATIC WINDS?

From the Greek for 'going downhill', a katabatic wind is also known as a drainage wind. It carries dense air down from high elevations, such as mountain tops, down a slope thanks to gravity. This is a common occurrence in places like Antarctica's Polar Plateau, where incredibly cold air on top of the plateau sinks and flows down through the rugged landscape, picking up speed as it goes. The opposite of katabatic winds are called anabatic, which are winds that blow *up* a steep slope.

DOES IT EVER SNOW IN AFRICA?

Several countries in Africa see snow – indeed, there are ski resorts in Morocco and regular snowfall in Tunisia. Algeria and South Africa also see snowfall on occasion. It once snowed in the Sahara, but it was gone within 30 minutes. There's even a little snowfall around the equator if you count snow-topped peaks.

WHAT COLOUR IS LIGHTNING?

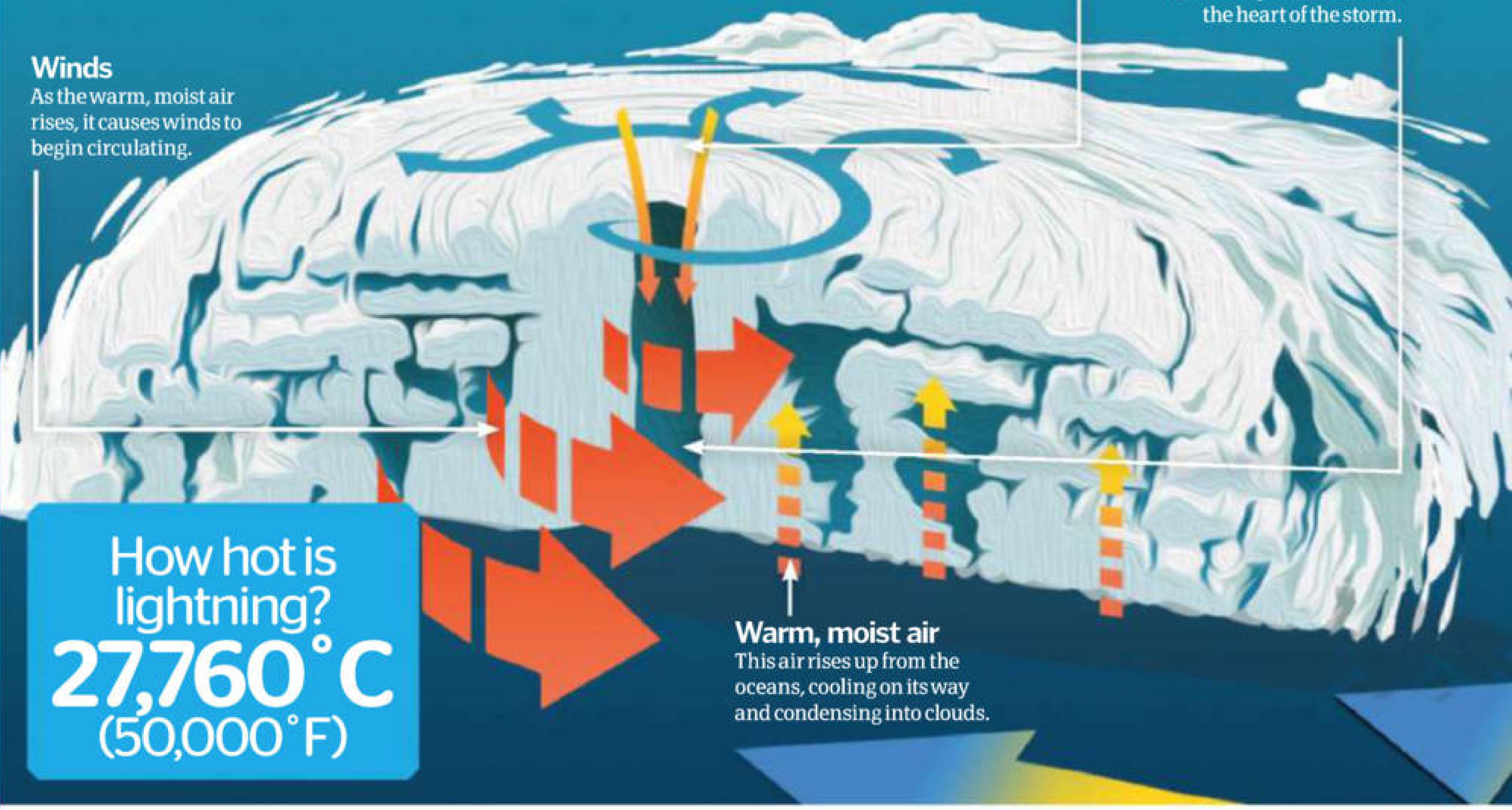
Usually lightning is white, but it can be any colour of the rainbow. There are a lot of factors that go into what hue the lightning will appear, including the amount of water vapour in the atmosphere, whether it's raining and the amount of pollution in the air. A high concentration of ozone, for example, can make it blue.

WHY DO SOME CITIES HAVE MICROCLIMATES?

Some large metropolises have microclimates – their own small climates that differ from the local environment. Often these are due to the massive amounts of concrete, asphalt and steel; these retain and reflect heat and do not absorb water, keeping a city warmer at night. This phenomenon specifically is often known as an urban heat island. Extreme energy use may contribute too.

What causes hurricanes?

Depending on where they start, hurricanes may also be known as tropical cyclones or typhoons. They always form over oceans around the equator, fuelled by the warm, moist air. As that air rises and forms clouds, more warm, moist air moves into the area of lower pressure below. As the cycle goes on, winds begin rotating and pick up speed. Once it hits 119 kilometres (74 miles) per hour, the storm is officially a hurricane. When hurricanes reach land, they weaken and die without the warm ocean air. Unfortunately they can move far inland before they run out of power, bringing a vast amount of rain and destructive winds that sweep through settled areas.



Cool, dry air
Cooled, dry air at the top of the system is sucked down in the centre, strengthening the winds.

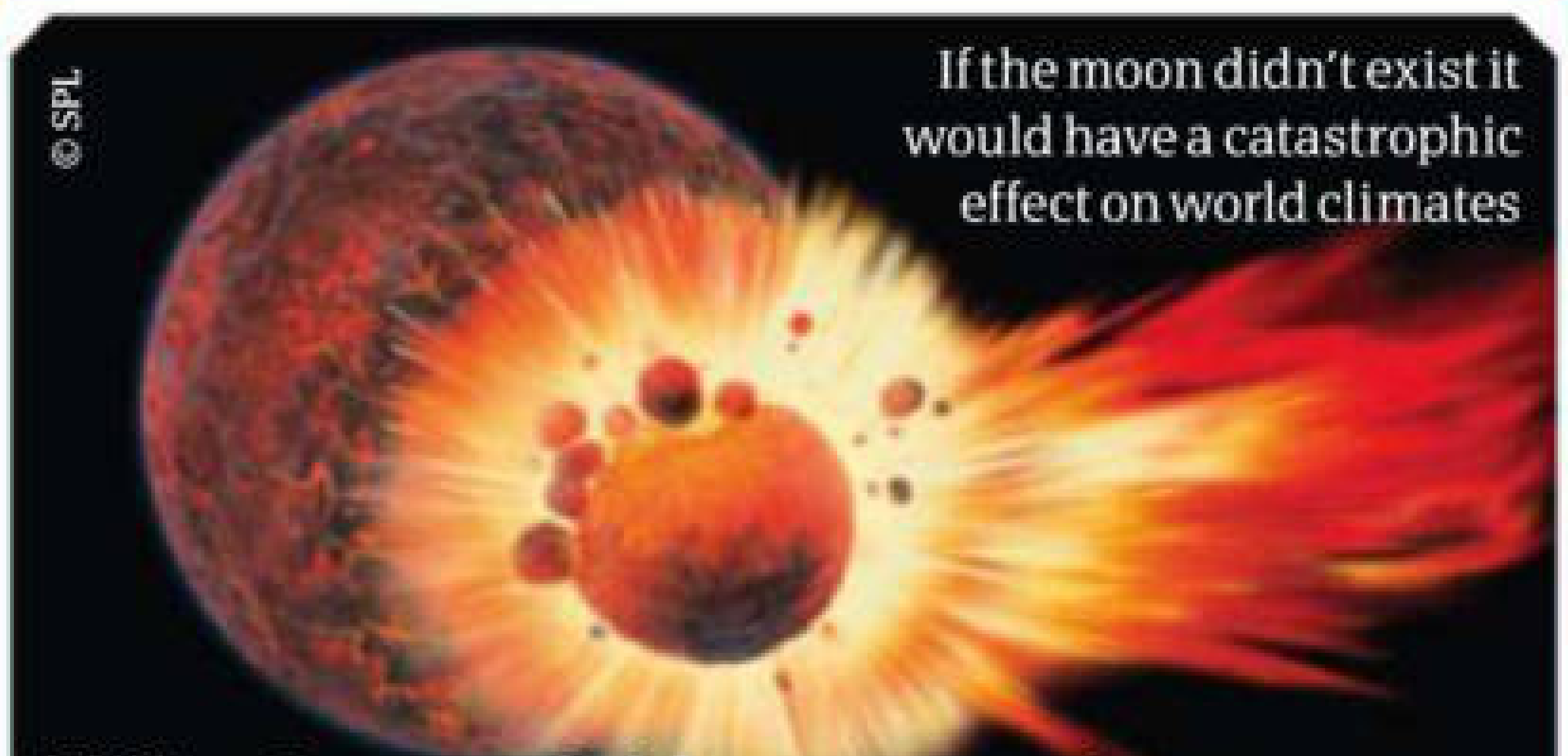
Eye
High-pressure air flows downward through this calm, low-pressure area at the heart of the storm.

Winds
As the warm, moist air rises, it causes winds to begin circulating.

Warm, moist air
This air rises up from the oceans, cooling on its way and condensing into clouds.

How hot is lightning?

27,760˚C (50,000˚F)



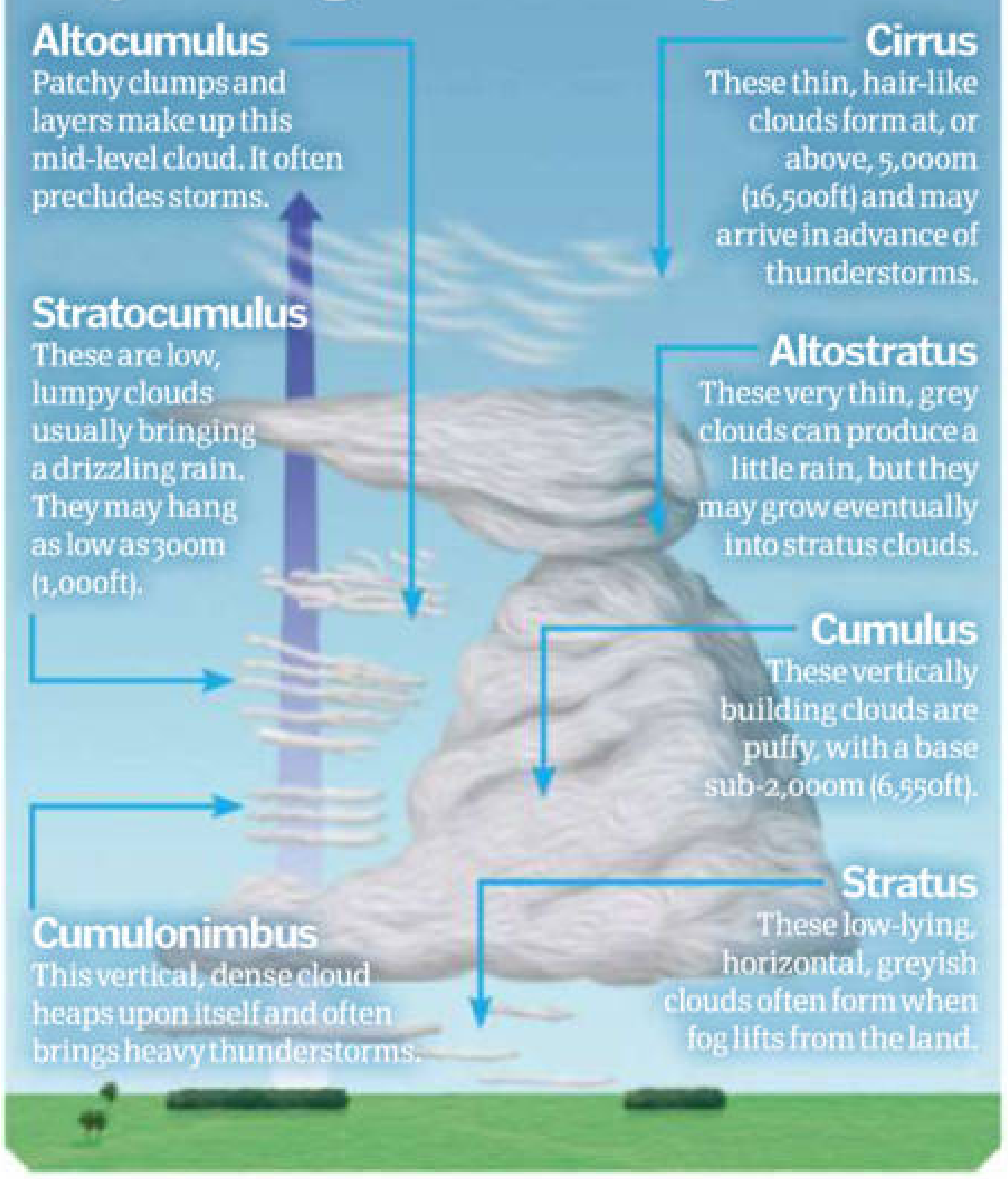
© SPL

If the moon didn't exist it would have a catastrophic effect on world climates

What would happen to our weather without the moon?

It's difficult to know exactly what would happen to our weather if the moon were destroyed, but it wouldn't be good. The moon powers Earth's tides, which in turn influence our weather systems. In addition, the loss of the moon would affect the Earth's rotation – how it spins on its axis. The presence of the moon creates a sort of drag, so its loss would probably speed up the rotation, changing the length of day and night. In addition it would alter the tilt of the Earth too, which causes the changes in our seasons. Some places would be much colder while others would become much hotter. Let's not neglect the impact of the actual destruction, either; that much debris would block out the Sun and rain down on Earth, causing massive loss of life. Huge chunks that hit the ocean could cause great tidal waves, for instance.

Why do clouds look different depending on their height?



Altocumulus
Patchy clumps and layers make up this mid-level cloud. It often precludes storms.

Stratocumulus
These are low, lumpy clouds usually bringing a drizzling rain. They may hang as low as 300m (1,000ft).

Cumulonimbus
This vertical, dense cloud heaps upon itself and often brings heavy thunderstorms.

Cirrus
These thin, hair-like clouds form at, or above, 5,000m (16,500ft) and may arrive in advance of thunderstorms.

Altostratus
These very thin, grey clouds can produce a little rain, but they may grow eventually into stratus clouds.

Cumulus
These vertically building clouds are puffy, with a base sub-2,000m (6,550ft).

Stratus
These low-lying, horizontal, greyish clouds often form when fog lifts from the land.

How many volts are in a lightning flash?

1 billion

Why are you safer inside a car during an electrical storm?

People used to think the rubber tyres on a car grounded any lightning that may strike it and that's what kept you safe. However, you're safer in your car during an electrical storm because of the metal frame. It serves as a conductor of electricity, and channels the lightning away into the ground without impacting anything – or anyone – inside; this is known as a Faraday cage. While it is potentially dangerous to use a corded phone or other appliances during a storm because lightning can travel along cables, mobile or cordless phones are fine. It's also best to avoid metallic objects, including golf clubs.

© SPL

What is ball lightning?

This mysterious phenomenon looks like a glowing ball of lightning and floats near the ground before disappearing, often leaving a sulphur smell. Despite many sightings, we're still not sure what causes it.

What causes giant hailstones?

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Put simply, giant hailstones come from giant storms – specifically a thunderstorm called a supercell. It has a strong updraft that forces wind upwards into the clouds, which keeps ice particles suspended for a long period. Within the storm are areas called growth regions; raindrops spending a long time in these are able to grow into much bigger hailstones than normal.

WHAT IS CLOUD IRIDESCENCE?

This happens when small water droplets or ice crystals in clouds scatter light, appearing as a rainbow of colours. It's not very common because the cloud has to be very thin, and even then colours are overshadowed by the Sun.

WHAT DO WEATHER SATELLITES DO?

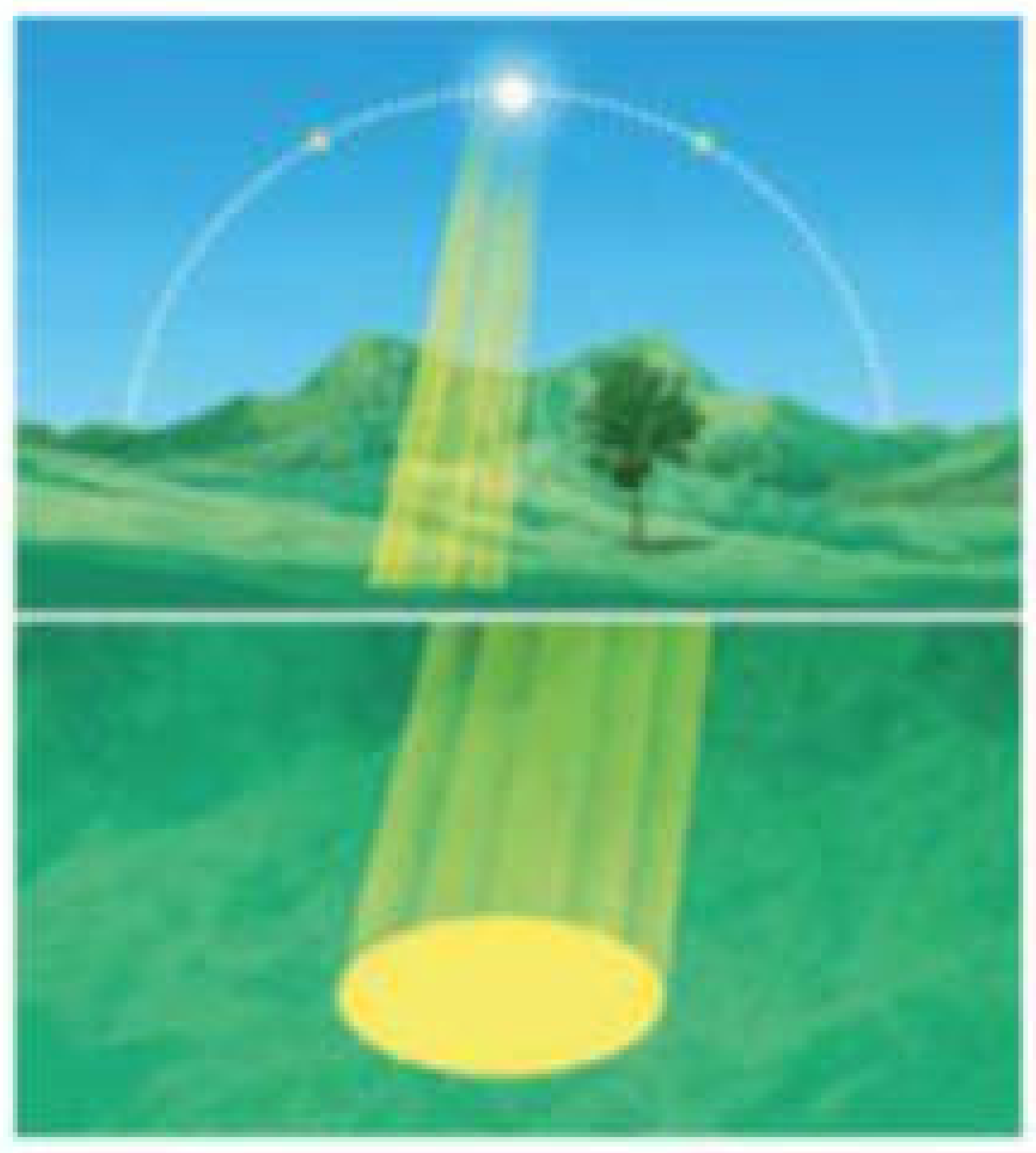
The GOES (Geostationary Operational Environmental Satellite) system run by the US National Environmental Satellite, Data, and Information Service (NESDIS) mainly comprises four geosynchronous satellites (although there are other geo-satellites, with other uses now or inactive). NOAA's National Weather Service use GOES for forecasting, meteorological research and storm tracking. The satellites give continuous Earth views, with data on temperature, cloud cover and air moisture, plus solar and near-space activities like solar flares and geomagnetic storms.

How does the Sun cause the seasons?

Seasons are caused by the Earth's revolution around the Sun, as well as the tilt of the Earth on its axis. The hemisphere receiving the most direct sunlight experiences spring and summer, while the other experiences autumn and winter. During the warmer months, the Sun is higher in the sky, stays above the horizon for longer, and its rays are more direct. During the cooler half, the Sun's rays aren't as strong and it's lower in the sky. The tilt causes these dramatic differences, so while those in the northern hemisphere are wrapping up for snow, those in the southern hemisphere may be sunbathing on the beach.

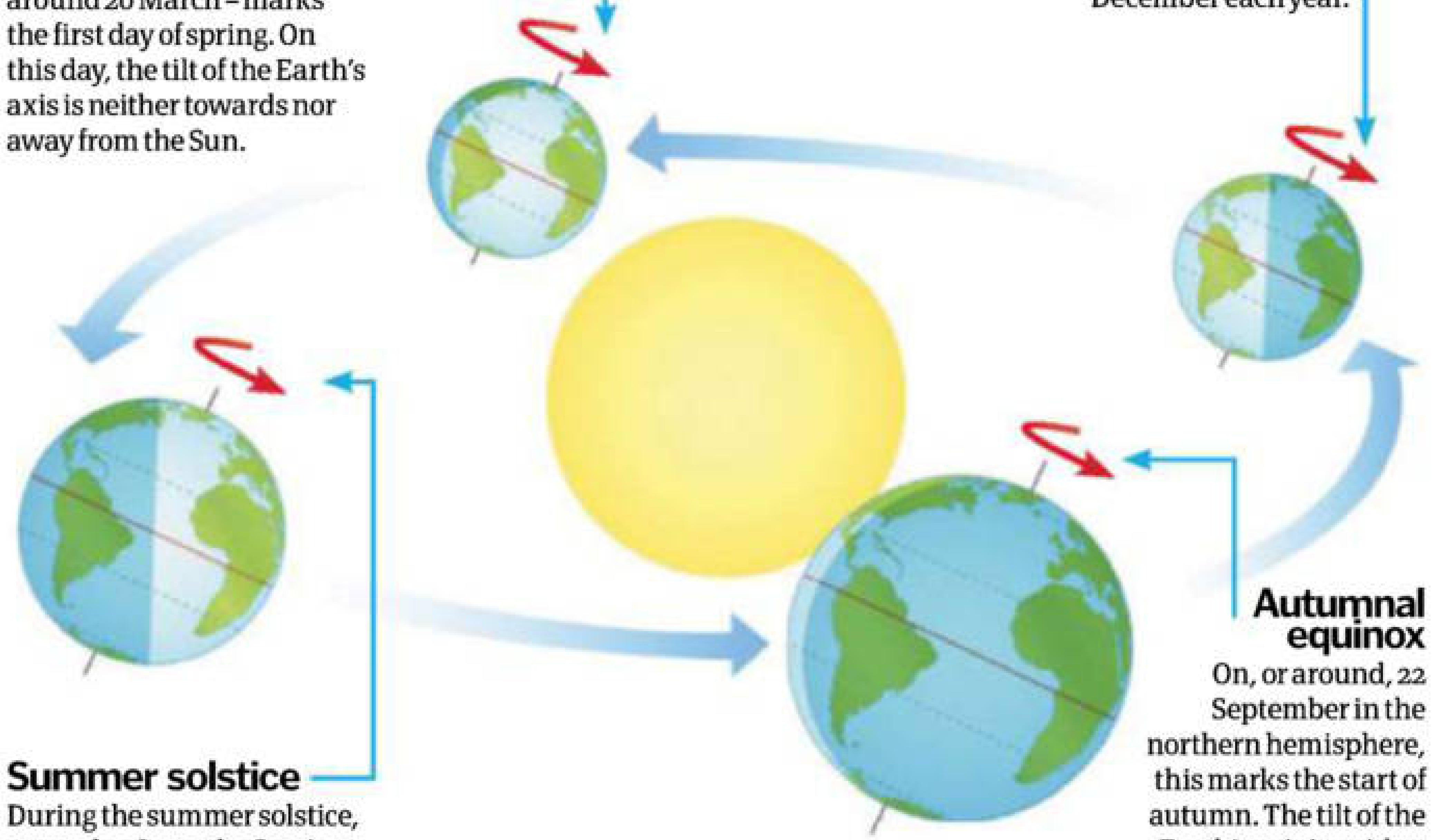
SUMMER

The Sun is at its highest point in the sky and takes up more of the horizon. Its rays are more direct.



WINTER

The Sun is at its lowest point in the sky and there is less daylight. The rays are also more diffuse.



Vernal equinox
For the northern hemisphere, this day – around 20 March – marks the first day of spring. On this day, the tilt of the Earth's axis is neither towards nor away from the Sun.

Winter solstice
The winter solstice marks the beginning of winter, with the Sun at its lowest point in the sky; it takes place around 20 December each year.

Summer solstice
During the summer solstice, around 20 June, the Sun is at its highest, or northernmost, point in the sky.

Autumnal equinox
On, or around, 22 September in the northern hemisphere, this marks the start of autumn. The tilt of the Earth's axis is neither towards nor away from the Sun.

WHY ARE RAINBOWS ARCH-SHAPED?

Rainbows are arched due to the way sunlight hits raindrops. It bends as it passes through because it slows during this process. Then, as the light passes out of the drop, it bends again as it returns to its normal speed.

WHY DOES IT SMELL FUNNY AFTER RAIN?

This scent comes from bacteria in the soil. Once the earth dries, the bacteria (called actinomycetes) release spores. Rainfall kicks these spores up into the air, and then the moist air disperses them. They tend to have a sweet, earthy odour.

HOW MUCH RAIN CAN A HURRICANE BRING?

The average hurricane, with a radius of about 1,330 kilometres (825 miles), can dump as much as 21.3×10^{15} cubic centimetres (1.3×10^{15} cubic inches) of water a day. That's enough rain to fill up 22 million Olympic-size swimming pools!

HOW DO DROUGHTS AND HEAT WAVES DIFFER?

Droughts are about an extreme lack of water, usually due to lower than average rainfall, and last for months or even years. There's no set definition of a heat wave, but it typically means higher than average temperatures for several consecutive days. Both can lead to crop failures and even fatalities.

How hot was the hottest day in history?

58°C (136°F)

Recorded on 13 September 1922 in Al Aziziyah, Libya

What's the difference between rain, sleet and snow?

When it comes to precipitation, it's all about temperature. When the air is sufficiently saturated, water vapour begins to form clouds around ice, salt or other cloud seeds. If saturation continues, water droplets grow and merge until they become heavy enough to fall as rain. Snow forms when the air is cold enough to freeze supercooled water droplets – lower than -31 degrees Celsius (-34 degrees Fahrenheit) – then falls. Sleet is somewhere in between: it starts as snow but passes through a layer of warmer air before hitting the ground, resulting in some snow melting.

What are gravity wave clouds?

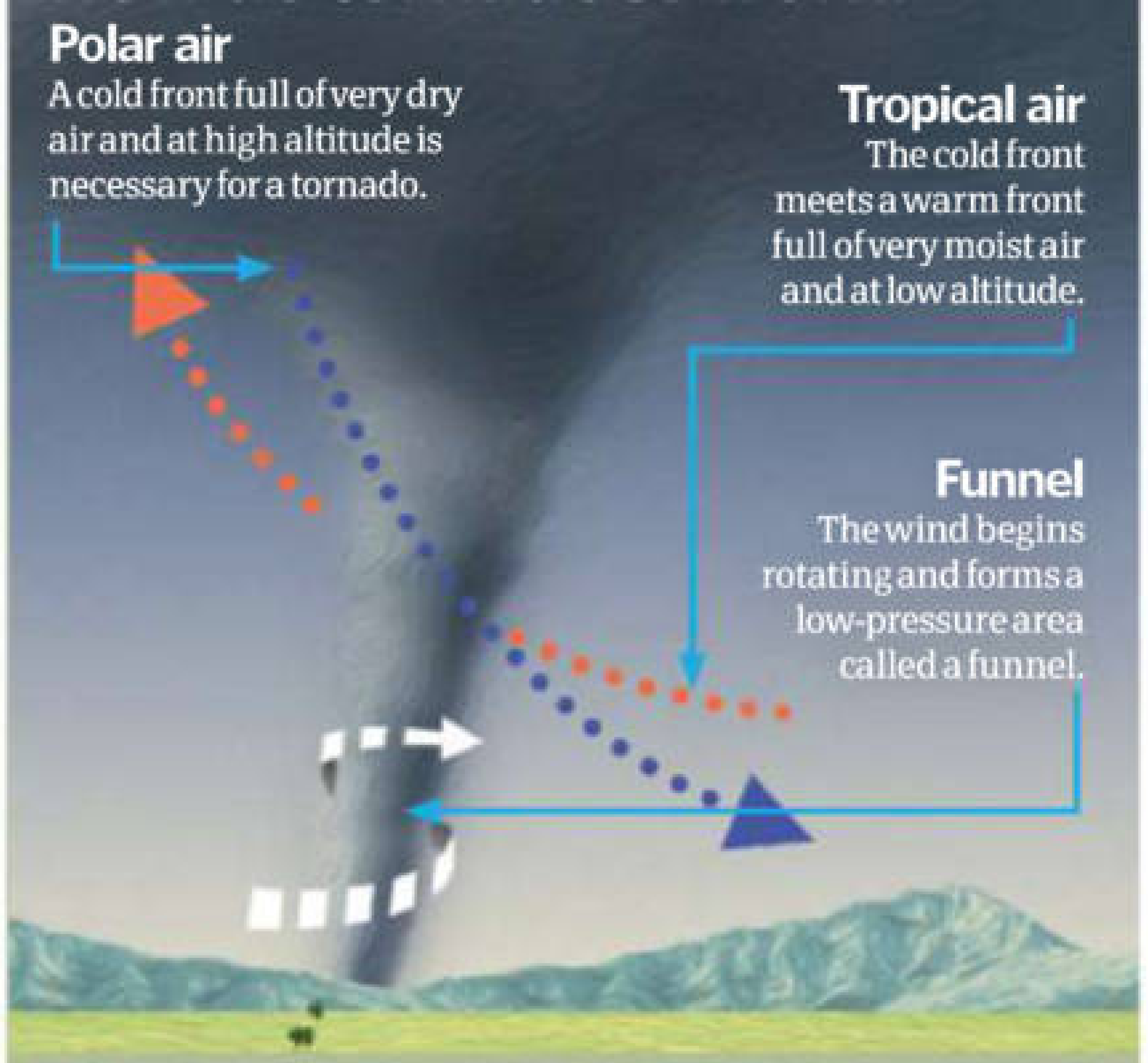
© SPL

Gravity waves are waves of air moving through a stable area of the atmosphere. The air might be displaced by an updraft or something like mountains as the air passes over. The upward thrust of air creates bands of clouds with empty space between them. Cool air wants to sink, but if it is buoyed again by the updraft, it will create additional gravity wave clouds.

Why is it so quiet after it snows?

It's peaceful after snowfall as the snow has a dampening effect; pockets of air between the flakes absorb noise. However, if it's compacted snow and windy, the snow might actually reflect sound.

How do tornadoes work?



Polar air
A cold front full of very dry air and at high altitude is necessary for a tornado.

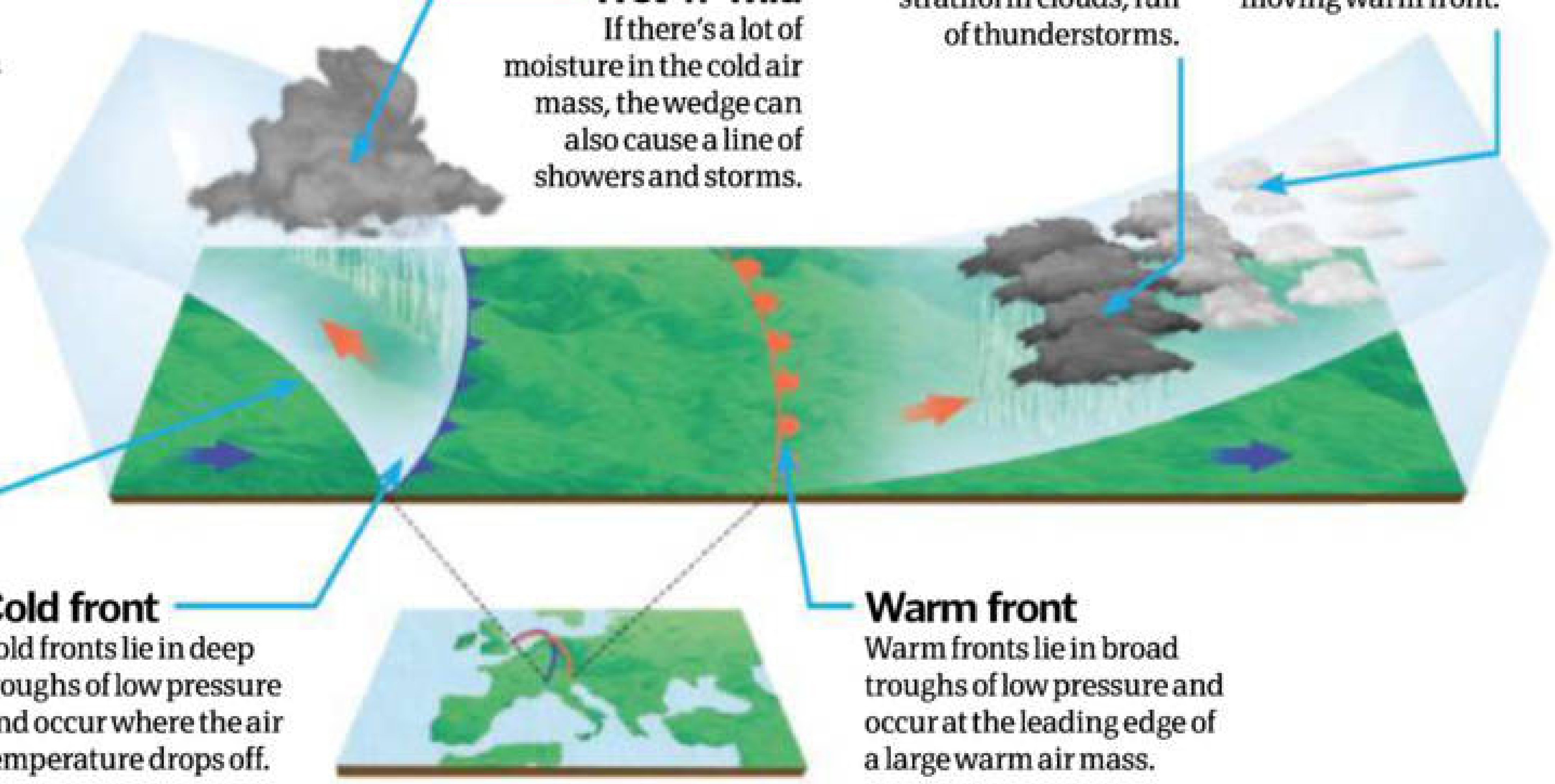
Tropical air
The cold front meets a warm front full of very moist air and at low altitude.

Funnel
The wind begins rotating and forms a low-pressure area called a funnel.

Tornadoes start out with severe thunderstorms called supercells. They form when polar air comes into contact with tropical air in a very unstable atmosphere. Supercells contain a rotating updraft of air that is known as a mesocyclone, which keeps them going for a long time. High winds add to the rotation, which keeps getting faster and faster until eventually it forms a funnel. The funnel cloud creates a sucking area of low pressure at the bottom. As soon as this funnel comes in to contact with the Earth, you have a tornado.

What is a weather front?

A weather front is the separation between two different masses of air, which have differing densities, temperature and humidity. On weather maps, they're delineated by lines and symbols. The meeting of different frontal systems causes the vast majority of weather phenomena.



Wet 'n' wild
If there's a lot of moisture in the cold air mass, the wedge can also cause a line of showers and storms.

Thunderstorms
Unstable masses of warm air often contain stratiform clouds, full of thunderstorms.

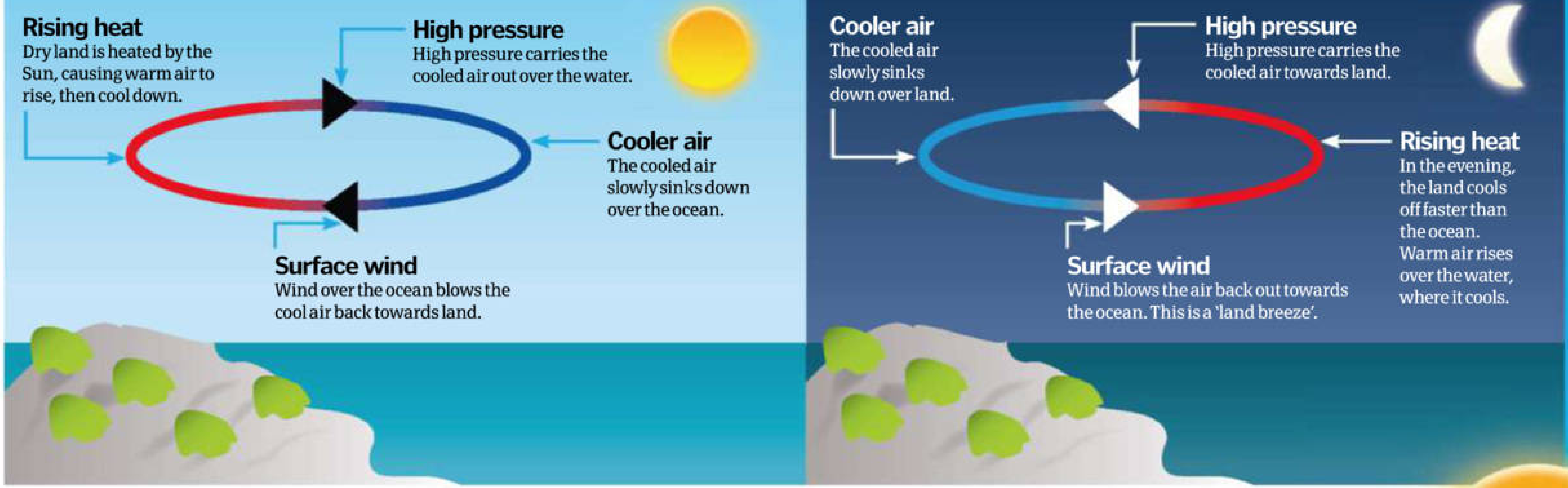
Fog
Fog often comes before the slow-moving warm front.

Wedge
As cold air is denser, it often 'wedges' beneath the warm air. This lift can cause wind gusts.

Cold front
Cold fronts lie in deep troughs of low pressure and occur where the air temperature drops off.

Warm front
Warm fronts lie in broad troughs of low pressure and occur at the leading edge of a large warm air mass.

What is a sea breeze?


Rising heat
Dry land is heated by the Sun, causing warm air to rise, then cool down.
High pressure
High pressure carries the cooled air out over the water.
Cooler air
The cooled air slowly sinks down over the ocean.
Surface wind
Wind over the ocean blows the cool air back towards land.
Cooler air
The cooled air slowly sinks down over land.
High pressure
High pressure carries the cooled air towards land.
Rising heat
In the evening, the land cools off faster than the ocean. Warm air rises over the water, where it cools.
Surface wind
Wind blows the air back out towards the ocean. This is a 'land breeze'.

What is the eye of a storm?

The eye is the calm centre of a storm like a hurricane or tornado, without any weather phenomena. Because these systems consist of circular, rotating winds, air is funnelled downward through the eye and feeds back into the storm itself.

The eye at the centre of a hurricane tends to be 20-50km (12-31mi) in diameter

© NASA

What are red sprites and blue jets?

© SPL

These are both atmospheric and electrical phenomena that take place in the upper atmosphere, and are also known as upper-atmosphere discharge. They take place above normal lightning; blue jets occur around 40-50 kilometres (25-30 miles) above the Earth, while red sprites are higher at 50-100 kilometres (32-64 miles). Blue jets happen in cone shapes above thunderstorm clouds, and are not related to lightning. They're blue due to ionised emissions from nitrogen. Red sprites can appear as different shapes and have hanging tendrils. They occur when positive lightning goes from the cloud to the ground.

Does lightning ever strike in the same place twice?

Yes, lightning often strikes twice in the same location. If there's a thunderstorm and lightning strikes, it's just as likely to happen again. Many tall structures get struck repeatedly during thunderstorms, such as New York City's famed Empire State Building or NASA's shuttle launch pad in Cape Canaveral, Florida.

How cold was the coldest day in history?

-89°C (-129°F)

Recorded on 21 July 1983 at Vostok II Station, Antarctica

Why does the Sun shine?

The Sun is a super-dense ball of gas, where hydrogen is continually burned into helium (nuclear fusion). This generates a huge deal of energy, and the core reaches 15 million degrees Celsius (27 million degrees Fahrenheit). This extreme heat produces lots of light.

WHY ARE CLOUDS FLUFFY?

Fluffy-looking clouds are called cumulus. They form when warm air rises from the ground, meets a layer of cool air and moisture condenses. If the cloud grows enough to meet an upper layer of freezing air, rain or snow may fall from the cloud.

WHAT IS ACID RAIN?

Acid rain is full of chemicals like nitrogen oxide, carbon dioxide and sulphur dioxide, which react with water in the rain. Much of it comes from coal powerplants, cars and factories. It can harm wildlife and also damage buildings.

WHY CAN I SEE MY BREATH IF IT'S COLD?

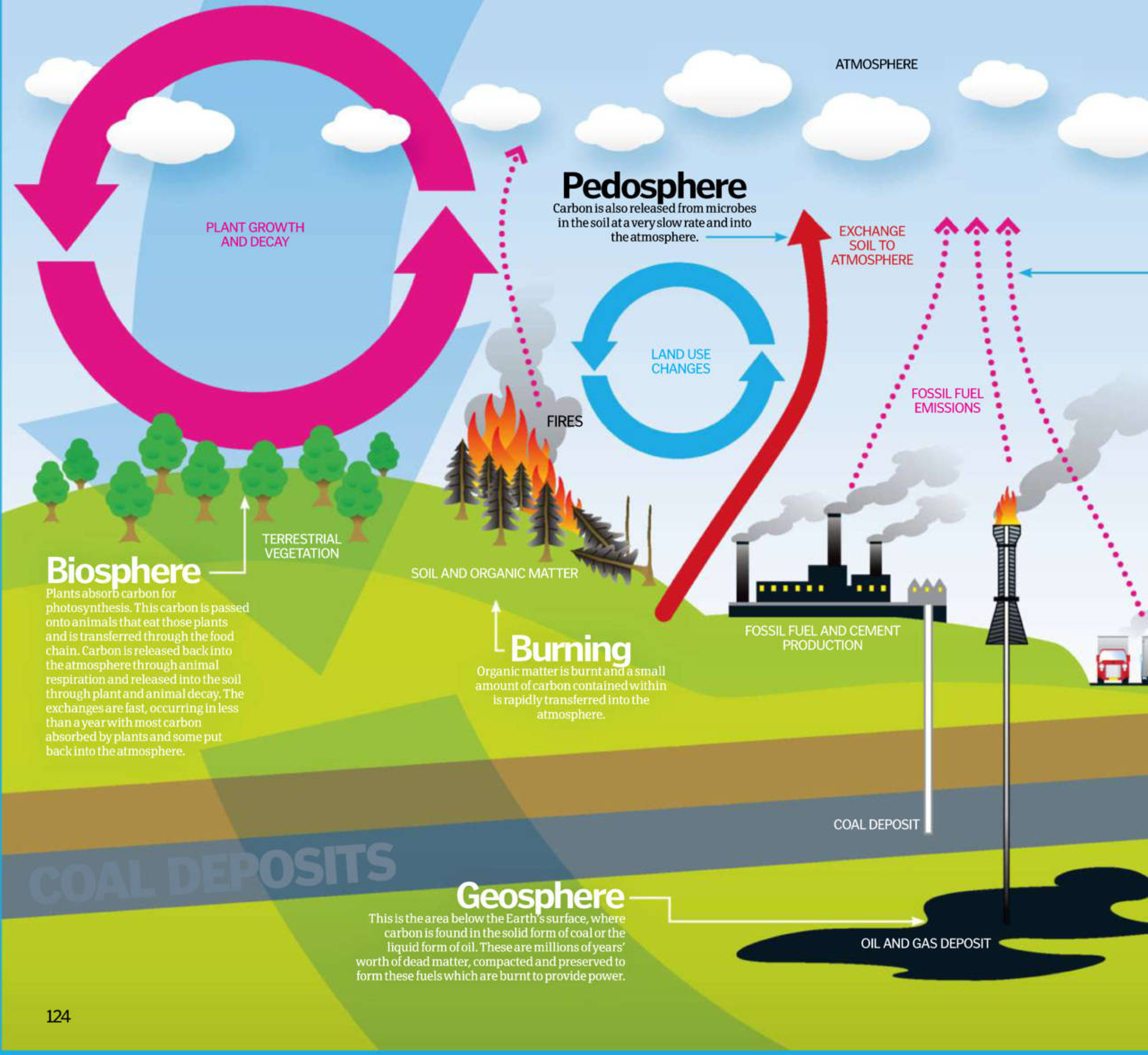
Breath is full of warm water vapour because your lungs are moist. When it's cold outside, that warm vapour cools as it hits the cold air. The water molecules slow down, begin to change form, and bunch up together, becoming visible.

WHAT IS THE GREEN FLASH YOU SOMETIMES SEE AS THE SUN SETS?

At sunsets (or indeed rises), the Sun occasionally changes colour due to refraction. This is known as a green flash, and only lasts for a second or two.

The carbon cycle

You're breathing it out right now, but where has it been before and where is it going next?



Pedosphere

Carbon is also released from microbes in the soil at a very slow rate and into the atmosphere.

Biosphere

Plants absorb carbon for photosynthesis. This carbon is passed onto animals that eat those plants and is transferred through the food chain. Carbon is released back into the atmosphere through animal respiration and released into the soil through plant and animal decay. The exchanges are fast, occurring in less than a year with most carbon absorbed by plants and some put back into the atmosphere.

Burning

Organic matter is burnt and a small amount of carbon contained within is rapidly transferred into the atmosphere.

Geosphere

This is the area below the Earth's surface, where carbon is found in the solid form of coal or the liquid form of oil. These are millions of years' worth of dead matter, compacted and preserved to form these fuels which are burnt to provide power.

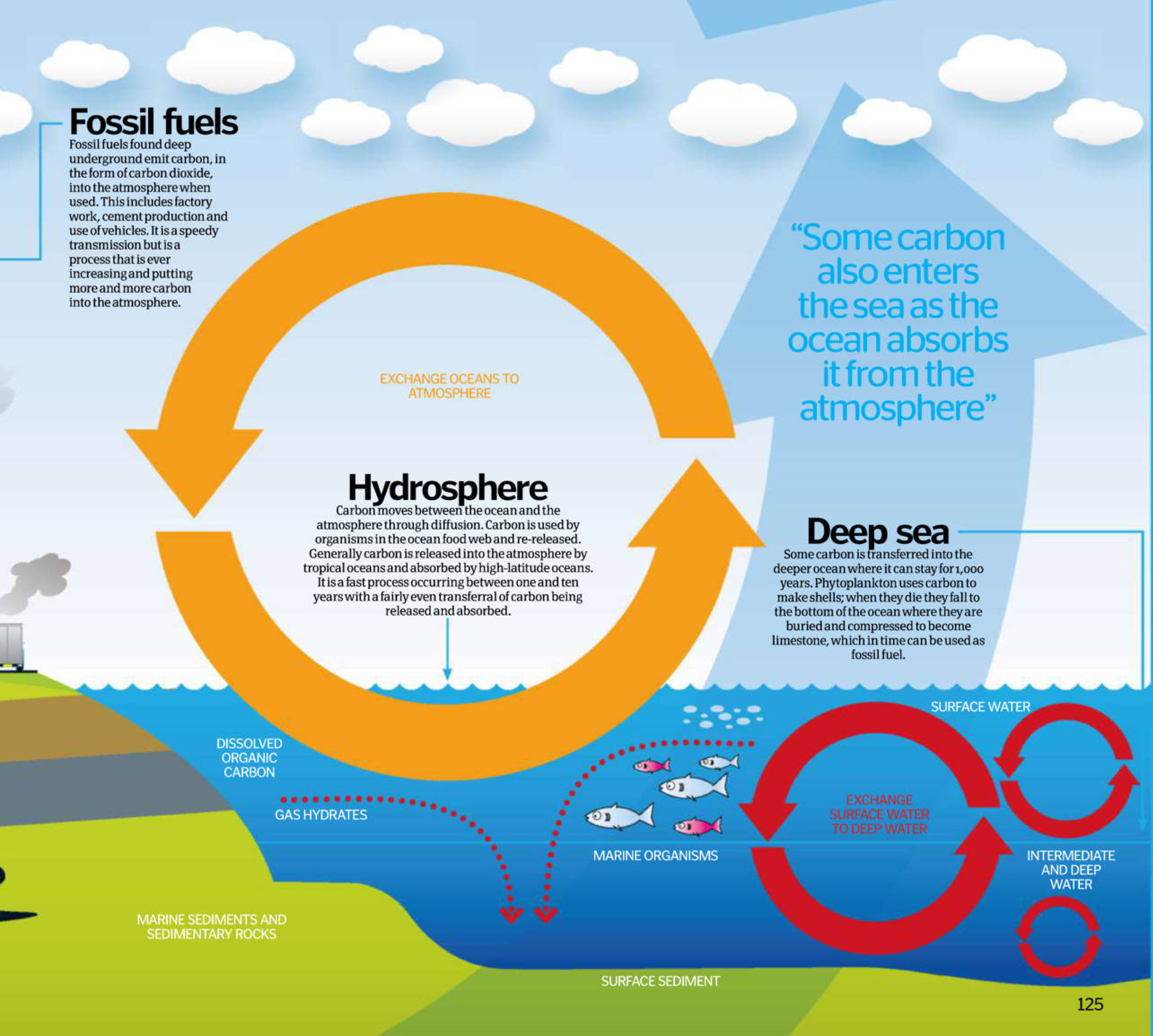
Carbon is a greenhouse gas that helps trap heat and keep the Earth warm. Just as water is transferred around the Earth, carbon atoms also follow a cycle and are used again and again in different environmental processes. You might not be able to see carbon but it is a vital part of how our world works and it moves around the Earth in a variety of ways.

Carbon moves from the atmosphere into plants. In the atmosphere it is combined with oxygen and found as carbon dioxide. Plant photosynthesis draws the carbon out of the air to make plant food. The carbon then moves from plants into animals as animals eat the plants. The carbon moves up the food chain as each animal is eaten by another. Animals release carbon back into the atmosphere through respiration when they breathe out CO$_2$.

When plants and animals die the carbon is transferred into the soil when decomposition occurs. Some of this carbon will end up buried miles underground and so will eventually make fossil fuels. These fossil fuels are then burned and used for power, in the form of factories, cars and so on, therefore releasing the carbon back into the atmosphere. Some carbon also enters the sea as the ocean absorbs it from the atmosphere.

Although the carbon cycle is a natural process it can be affected by human activity; our burning of fossil fuels means there is 30 per cent more carbon dioxide in the air now than 150 years ago.

Exchange rates 🟪 **VERY FAST** (< 1 year) 🟧 **FAST** (1 to 10 years) 🟦 **SLOW** (10 to 100 years) 🟥 **VERY SLOW** (> 100 years)


EXCHANGE OCEANS TO ATMOSPHERE
SURFACE WATER
DISSOLVED ORGANIC CARBON
GAS HYDRATES
MARINE ORGANISMS
EXCHANGE SURFACE WATER TO DEEP WATER
INTERMEDIATE AND DEEP WATER
MARINE SEDIMENTS AND SEDIMENTARY ROCKS
SURFACE SEDIMENT

Fossil fuels

Fossil fuels found deep underground emit carbon, in the form of carbon dioxide, into the atmosphere when used. This includes factory work, cement production and use of vehicles. It is a speedy transmission but is a process that is ever increasing and putting more and more carbon into the atmosphere.

> "Some carbon also enters the sea as the ocean absorbs it from the atmosphere"

Hydrosphere

Carbon moves between the ocean and the atmosphere through diffusion. Carbon is used by organisms in the ocean food web and re-released. Generally carbon is released into the atmosphere by tropical oceans and absorbed by high-latitude oceans. It is a fast process occurring between one and ten years with a fairly even transferral of carbon being released and absorbed.

Deep sea

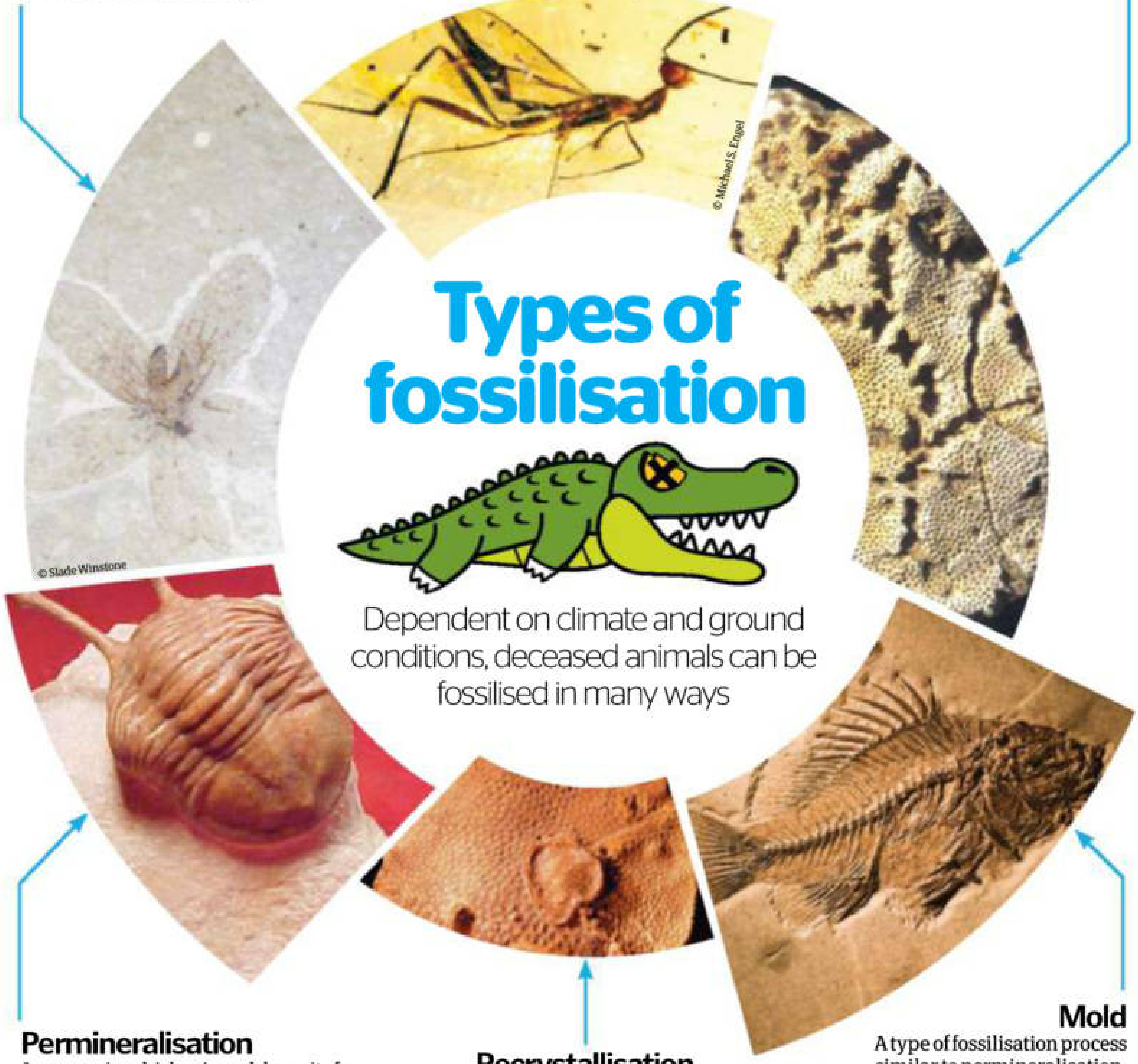
Some carbon is transferred into the deeper ocean where it can stay for 1,000 years. Phytoplankton uses carbon to make shells; when they die they fall to the bottom of the ocean where they are buried and compressed to become limestone, which in time can be used as fossil fuel.

What are fossils?

Obliterating the traditional perception of the origins and evolution of life on Earth, fossils grant us unique snapshots of what once lived on our ever-changing planet

Types of fossilisation

Dependent on climate and ground conditions, deceased animals can be fossilised in many ways



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Adpression
A form of fossilisation caused by compression within sedimentary rock. This type of fossilisation occurs mainly where fine sediment is deposited frequently, such as along rivers. Many fossilised plants are formed this way.

Resin
Referred to as amber, fossil resin is a natural polymer excreted by trees and plants. As it is sticky and soft when produced, small invertebrates such as insects and spiders are often trapped and sealed within resin, preserving their form.

Bioimmuration
Bioimmuration is a type of fossil that in its formation subsumes another organism, leaving an impression of it within the fossil. This type of fossilisation usually occurs between sessile skeletal organisms, such as oysters.

Permineralisation
A process in which mineral deposits form internal casts of organisms, permineralisation works when a deceased animal dies and then is rapidly submerged in groundwater. The water fills the creature's lungs and empty spaces, before draining away leaving a mineral cast.

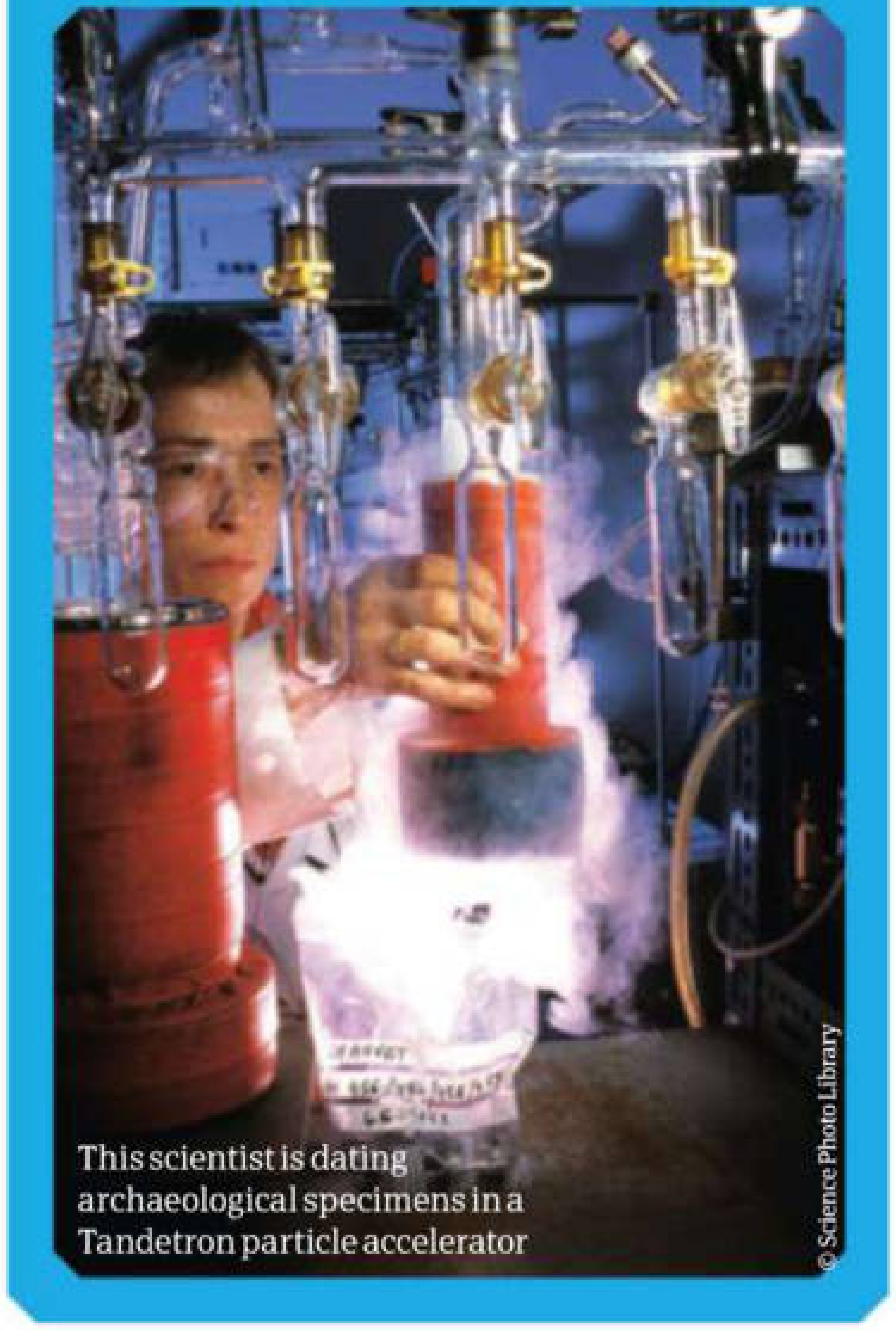
Recrystallisation
When a shelled creature's shell, bone or tissue maintains its original form but is replaced with a crystal – such as aragonite and calcite – then it is said to be recrystallised.

Mold
A type of fossilisation process similar to permineralisation, molds occur when an animal is completely dissolved or destroyed, leaving only an organism-shaped hole in the rock. Molds can turn into casts if they are then filled with minerals.

Carbon dating

A crucial tool for palaeontologists, carbon dating allows ancient fossils to be accurately dated

Carbon dating is a method of radioactive dating used by palaeontologists that utilises the radioactive isotope carbon-14 to determine the time since it died and was fossilised. When an organism dies it stops replacing carbon-14, which is present in every carbonaceous organism on Earth, leaving the existing carbon-14 to decay. Carbon-14 has a half-life (the time it takes a decaying object to decrease in radioactivity by 50 per cent) of 5,730 years, so by measuring the decayed levels of carbon-14 in a fossil, its time of death can be extrapolated and its geological age determined.



This scientist is dating archaeological specimens in a Tandetron particle accelerator

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The origin of life on Earth is irrevocably trapped in deep time. The epic, fluid and countless beginnings, evolutions and extinctions are immeasurable to humankind; our chronology is fractured, the picture is incomplete. For while the diversity of life on Earth today is awe-inspiring, with animals living within the most extreme environments imaginable – environments we as humans brave every day in a effort to chart and understand where life begins and ends – it is but only a fraction of the total life Earth has seen inhabit it over geological time. Driven by the harsh realities of an ever-changing environment, Armageddon-level extinction events and the perpetual, ever-present force of natural selection, wondrous creatures with five eyes, fierce predators with 12-inch fangs and massive creatures twice the size of a double-decker bus have long since ceased to exist. They're forgotten, buried by not just millions, but billions of years. Still, all is not lost. By exploiting Earth's natural processes and modern technology over the last two hundred years, scientists and palaeontologists have begun to unravel Earth's tree of life and, through the discovery and excavation of fossils – preserved remains and traces of past life in Earth's crust – piece the jigsaw back together.

> "The softer parts of fossilised creatures tend not to survive due to the rapidity of decay"

The fossilisation of an animal can occur in a variety of ways (see 'Types of fossilisation' diagram) but, in general, it occurs when a recently deceased creature is rapidly buried by sediment or subsumed in an oxygen-deficient liquid. This has the effect of preserving parts of the creature – usually the harder, solid parts like its skeleton – often in the original, living form within the Earth's crust. The softer parts of fossilised creatures tend not to survive due to the speed of decay and their replacement by minerals contained in their sediment or liquid casing, a process that can leave casings and impressions of the animal that once lived, but not its remains. Importantly, however, creature fossilisation tends to ▶

be specific to the environmental conditions in which it lived – and these in themselves are indicative of certain time periods in Earth's geological history. For example, certain species of trilobite (an extinct marine arthropod) are only found in certain rock strata (layers of sedimentary and igneous rocks formed through mineral deposition over millions of years), which itself is identifiable by its materials and mineralogic composition. This allows palaeontologists to extrapolate the environmental conditions (hot, cold, dry, wet, etc) that the animal lived and died in and, in partnership with radiometric dating, assign a date to the fossil and/or the period.

Interestingly, however, by studying the strata and the contained fossils over multiple layers, through a mixture of this form of palaeontology and phylogenetics (the study of evolutionary relatedness between organism groups), scientists can chart the evolution of animals over geological time scales. A good example of this process is the now known transition of certain species of dinosaur into birds. Here, by dating and analysing specimens such as archaeopteryx – a famous dinosaur/bird transition fossil – both by strata and by radiometric methods, as well as recording their molecular and morphological data, scientists can then chart its progress through strata layers to the present day. In addition, by following the fossil record in this way, palaeontologists can also attribute the geophysical/chemical changes to the rise, fall or transition of any one animal/plant group, reading the sediment's composition and structural data. For example, the Cretaceous-Tertiary extinction event is identified in sedimentary strata by a sharp decline in species' diversity – notably non-avian dinosaurs – and increased calcium deposits from dead plants and plankton.

Excavating any discovered fossil in order to date and analyse it is a challenging, time-consuming process, which requires special tools and equipment. These include picks and shovels, trowels, whisks, hammers, dental drills and even explosives. There is also an accepted academic method all professional palaeontologists follow when preparing, removing and transporting any discovered fossil. First, the fossil is partially freed from the sedimentary matrix it is encased in and labelled, photographed and reported. Next, the overlying rock (commonly referred to as the 'overburden') is removed using large tools up to a distance of two to three inches from the fossil, before it is once again photographed. Then, depending on the stability of the fossil, it is coated with a thin glue via brush or aerosol in order to strengthen its structure, before being wrapped in a series of paper, bubble wrap and Hessian cloth. Finally, it is transported to the laboratory.

The fossil record

By examining discovered fossils, it is possible to piece together a rough history of the development of life on Earth over a geological timescale

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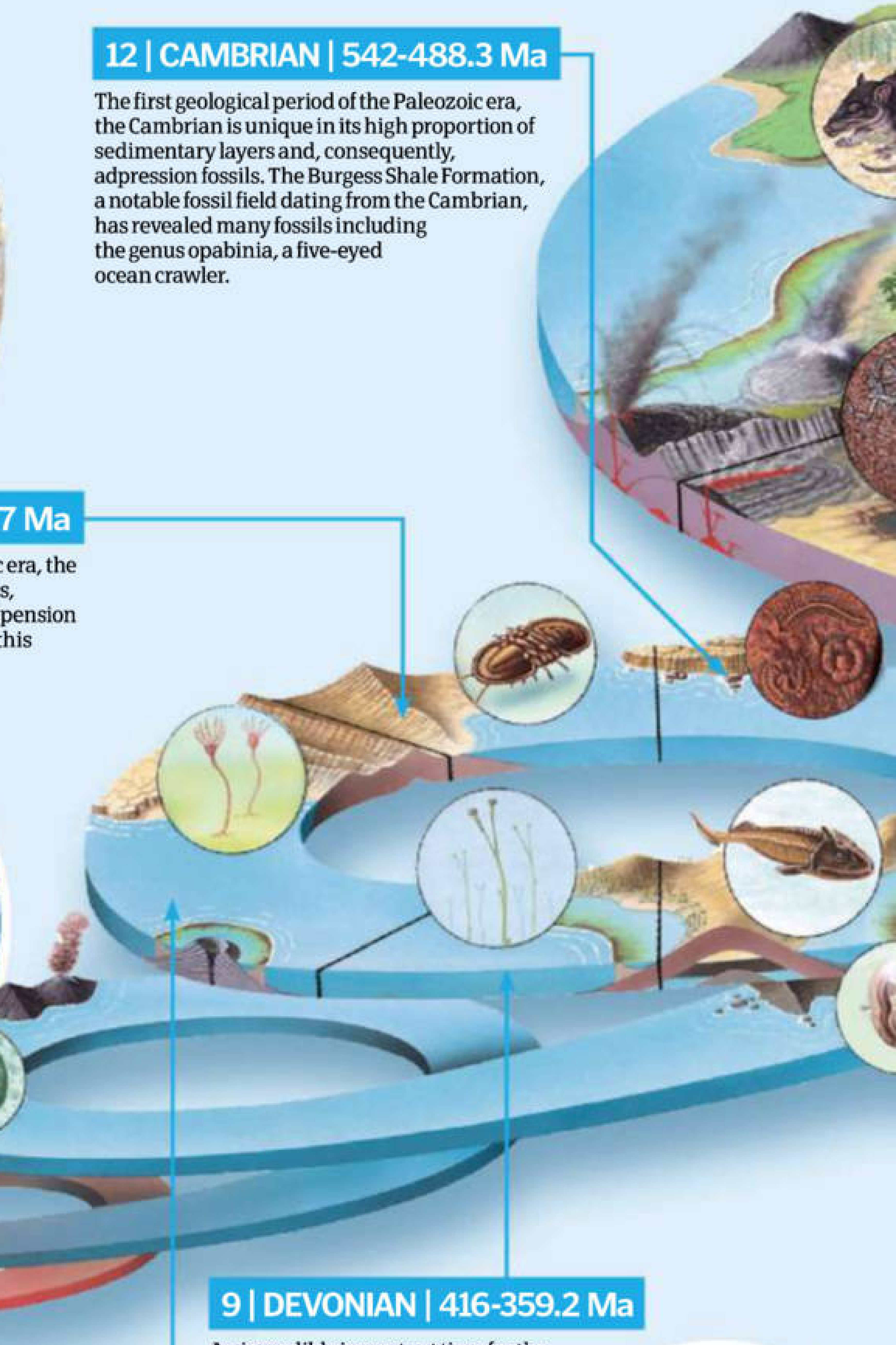


12 | CAMBRIAN | 542-488.3 Ma

The first geological period of the Paleozoic era, the Cambrian is unique in its high proportion of sedimentary layers and, consequently, adpression fossils. The Burgess Shale Formation, a notable fossil field dating from the Cambrian, has revealed many fossils including the genus opabinia, a five-eyed ocean crawler.

11 | ORDOVICIAN | 488.3-443.7 Ma

Boasting the highest sea levels of the Palaezoic era, the Ordovician saw the proliferation of planktonics, brachiopods and cephalopods. Nautiloids, suspension feeders, are among the largest creatures from this period to be discovered.

© Jlorenzi

10 | SILURIAN | 443.7-416 Ma

With its base set at a major extinction event at the end of the Ordovician, the silurian fossils found differ markedly from those that pre-date the period. Notable life developments include the first bony fish, and organisms with moveable jaws.

9 | DEVONIAN | 416-359.2 Ma

An incredibly important time for the development of life, the Devonian period has relinquished fossils demonstrating the evolution of the pectoral and pelvic fins of fish into legs. The first land-based creatures, tetrapods and arthopods, become entrenched and seed-bearing plants spread across dry lands. A notable find is the genus tiktaalik.

© J.M.Luijt

3 | PALEOGENE | 65.5-23.03 Ma

The first period of the Cenozoic era, the Paleogene is notable for the rise of mammals as the dominant animal group on Earth, driven by the Cretaceous-Tertiary extinction event that wiped out the dinosaurs. The most important fossil to be discovered from this period is darwinius, a lemur-like creature uncovered from a shale quarry in Messel, Germany.

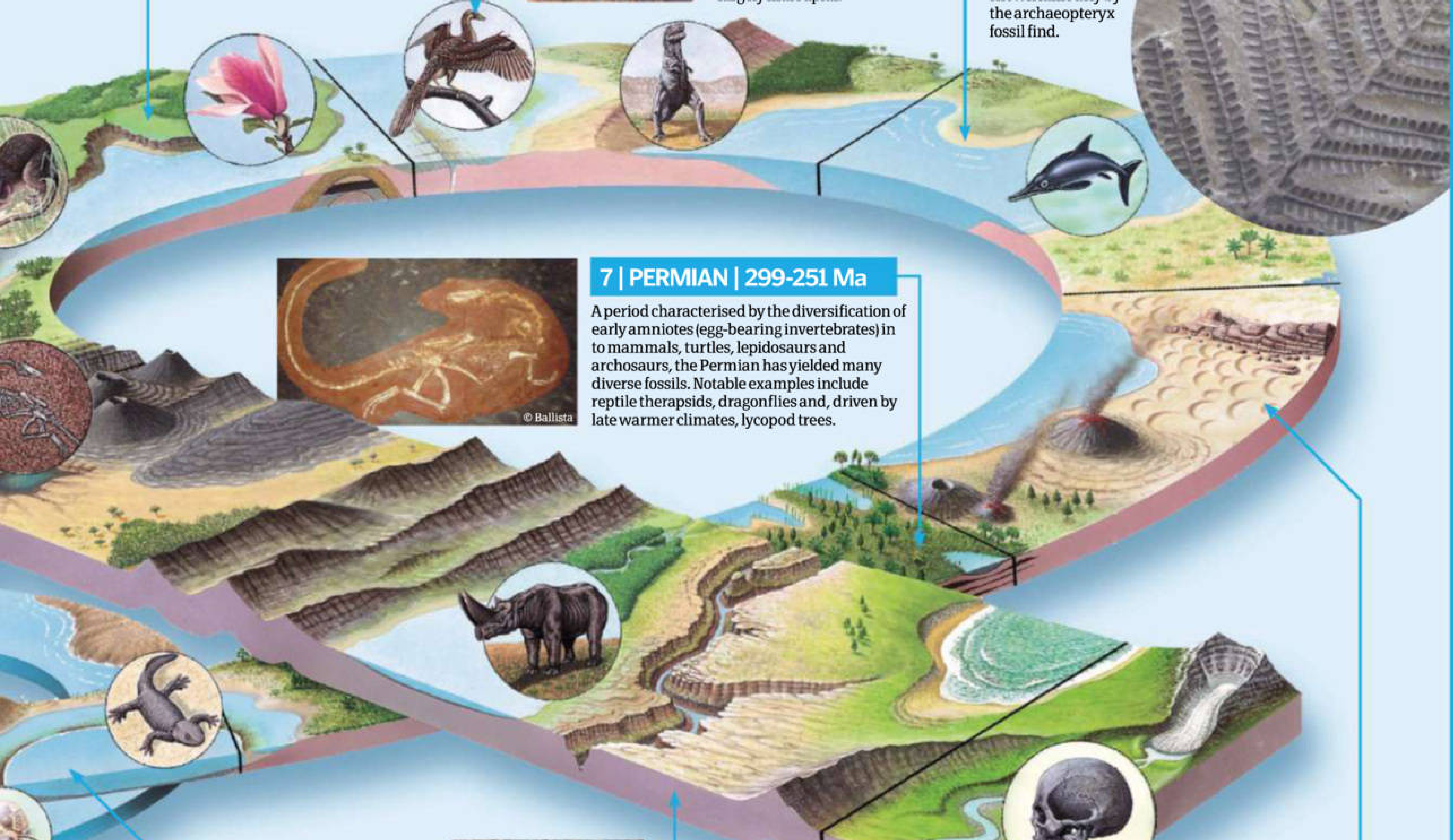
4 | CRETACEOUS | 145.5-65.5 Ma

© Petter Bøckman

Fossils discovered from the cretaceous indicate an explosion of insect diversification, with the first ants and grasshoppers evolving, as well as the dominance of large dinosaurs such as the colossal tyrannosaurus rex. Mammals increased in diversity, yet they remained small and were largely marsupial.

5 | JURASSIC | 199.6-145.5 Ma

The period in Earth's history when the supercontinent Pangaea broke up in to the northern Laurasia and southern Gondwana, the Jurassic saw an explosion in marine and terrestrial life. The fossil record points to dinosaurs thriving, such as megalosaurus, an increase in large predatory fish like ichthyosaurus, as well as the evolution of the first birds – shown famously by the archaeopteryx fossil find.



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7 | PERMIAN | 299-251 Ma

A period characterised by the diversification of early amniotes (egg-bearing invertebrates) in to mammals, turtles, lepidosaurs and archosaurs, the Permian has yielded many diverse fossils. Notable examples include reptile therapsids, dragonflies and, driven by late warmer climates, lycopod trees.

8 | CARBONIFEROUS | 359.2-299 Ma

A period of significant glaciation, the Carboniferous saw the development of ferns and conifers, bivalve molluscs and a wide-variety of basal tetrapods such as labyrinthodontia. Notable fossilised finds include the seed ferns pecopteris and neuropteris.

© Fritz Geller-Grimm

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2 | NEOGENE | 23.03-2.588 Ma

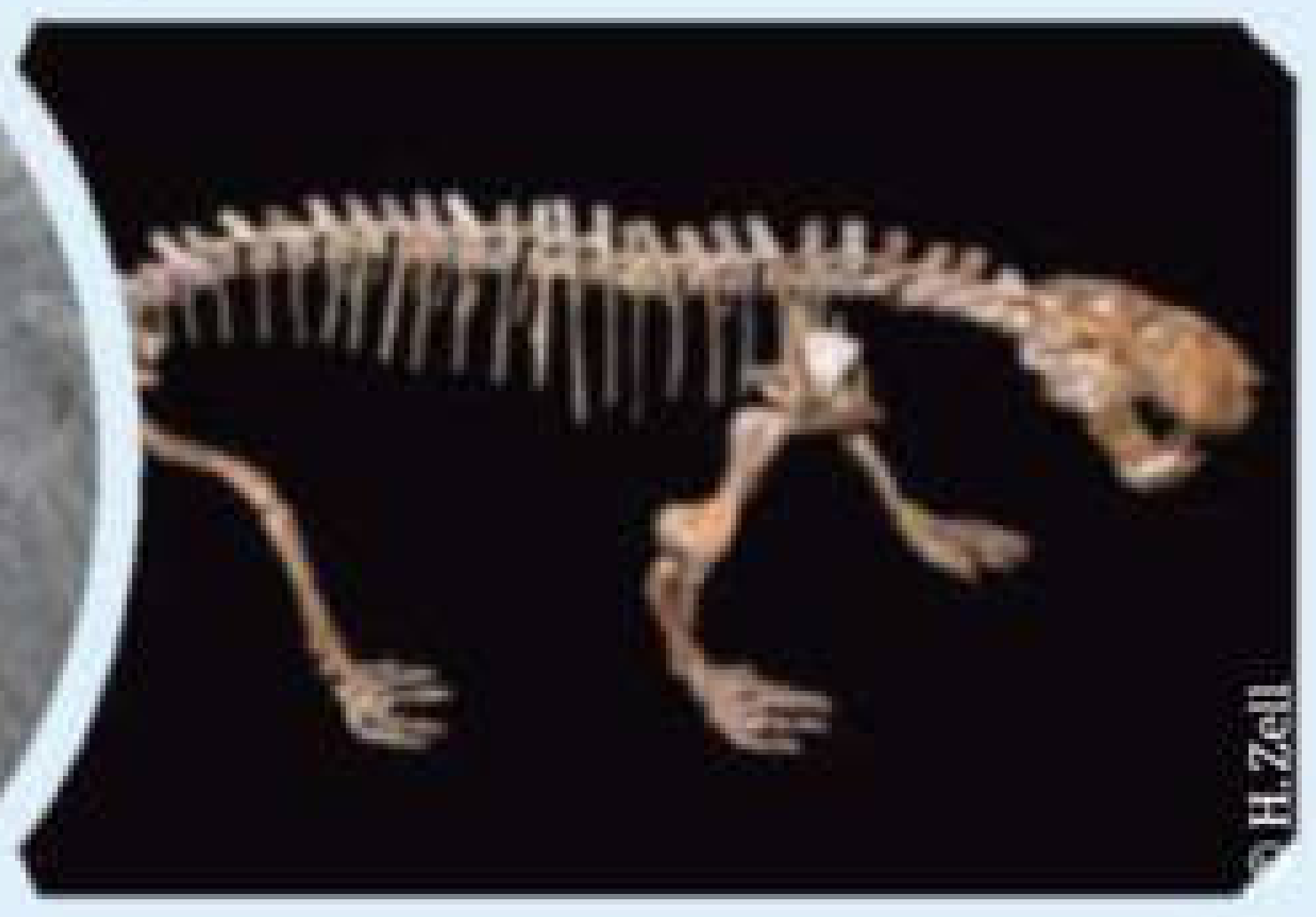
Covering 23 million years, the Neogene period's fossils show a marked development in mammals and birds, with many hominin remains excavated. The extinct hominid australopithecus afarensis – a common ancestor of the genus homo (that of modern humans) – is one of the most notable fossil finds, as exemplified in the specimens Lucy and Selam.

1 | QUATERNARY | 2.588-0.00 Ma

The most recent period in Earth's history, the Quaternary is characterised by major changes in climate, as well as the evolution and dispersement of modern humans. Due to the rapid changes in environment and climate (ie, ice ages), many larger mammal fossils have been discovered, including those of mammoths and sabre-toothed cats.

6 | TRIASSIC | 250-200 Ma

Beginning and ending with an extinction event, the Triassic period's fossils show the evolution of the first dinosaurs such as Coelophysis, a small carnivorous biped animal. Fossil evidence also shows the development of modern corals and reefs.



© H. Zell

Earth's minerals

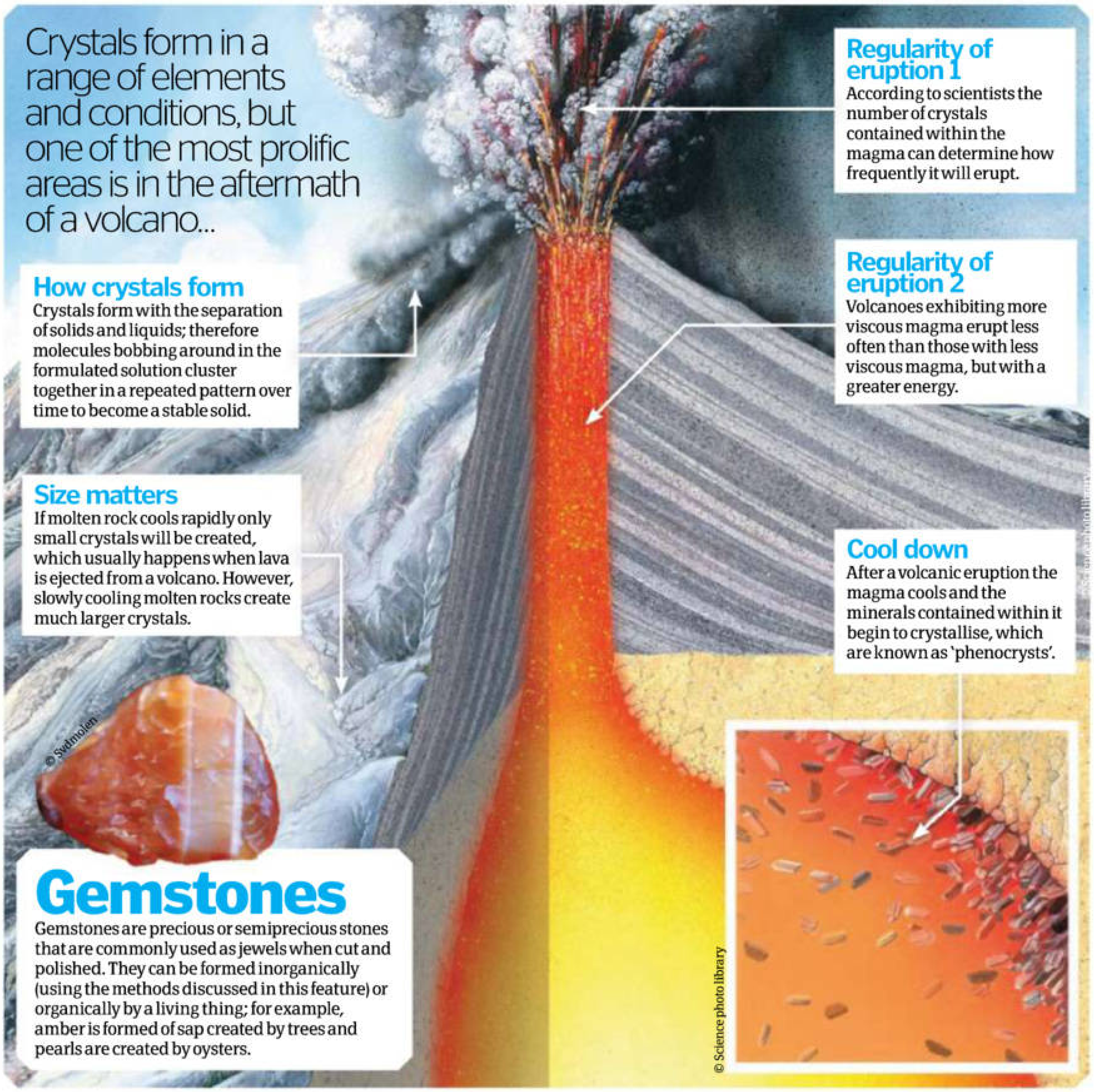
Crystals can take many forms, but how they come to be is a mystery for many. We find out exactly how they are made...

The term 'crystal' is used to describe a solid object that has been created by a structured repeating pattern of the same atoms or molecules.

Crystals 'build' using a process known as nucleation, which involves the attraction of molecules to one place to form a cluster. This can be achieved independently, which is referred to as 'unassisted nucleation', where solute (molecules) dissolved in the solvent collect together on their own; gradually attracting and amassing more particles, therefore growing in size and shape. Assisted nucleation sees the molecules collate using some form of solid matter, such as rock, as a type of collection point.

If the molecules remain joined, undisturbed and don't dissolve back into the surrounding solution, a stable nuclei will form, which attracts more of the same atoms. As this continues to build, the crystal will eventually reach its 'critical cluster size' and will not dissolve back into the solution from which it came.

Environmental factors such as pressure, space, temperature and chemical conditions present in the minerals can influence the way a crystal forms, but ultimately a crystal's shape is formed as molecules collect in a specific pattern that repeats itself over and over. As atoms join to all of its sides in the same pattern, geometric shapes are formed.



Crystals form in a range of elements and conditions, but one of the most prolific areas is in the aftermath of a volcano...

How crystals form
Crystals form with the separation of solids and liquids; therefore molecules bobbing around in the formulated solution cluster together in a repeated pattern over time to become a stable solid.

Size matters
If molten rock cools rapidly only small crystals will be created, which usually happens when lava is ejected from a volcano. However, slowly cooling molten rocks create much larger crystals.

Regularity of eruption 1
According to scientists the number of crystals contained within the magma can determine how frequently it will erupt.

Regularity of eruption 2
Volcanoes exhibiting more viscous magma erupt less often than those with less viscous magma, but with a greater energy.

Cool down
After a volcanic eruption the magma cools and the minerals contained within it begin to crystallise, which are known as 'phenocrysts'.

© Swdmolen

Gemstones

Gemstones are precious or semiprecious stones that are commonly used as jewels when cut and polished. They can be formed inorganically (using the methods discussed in this feature) or organically by a living thing; for example, amber is formed of sap created by trees and pearls are created by oysters.

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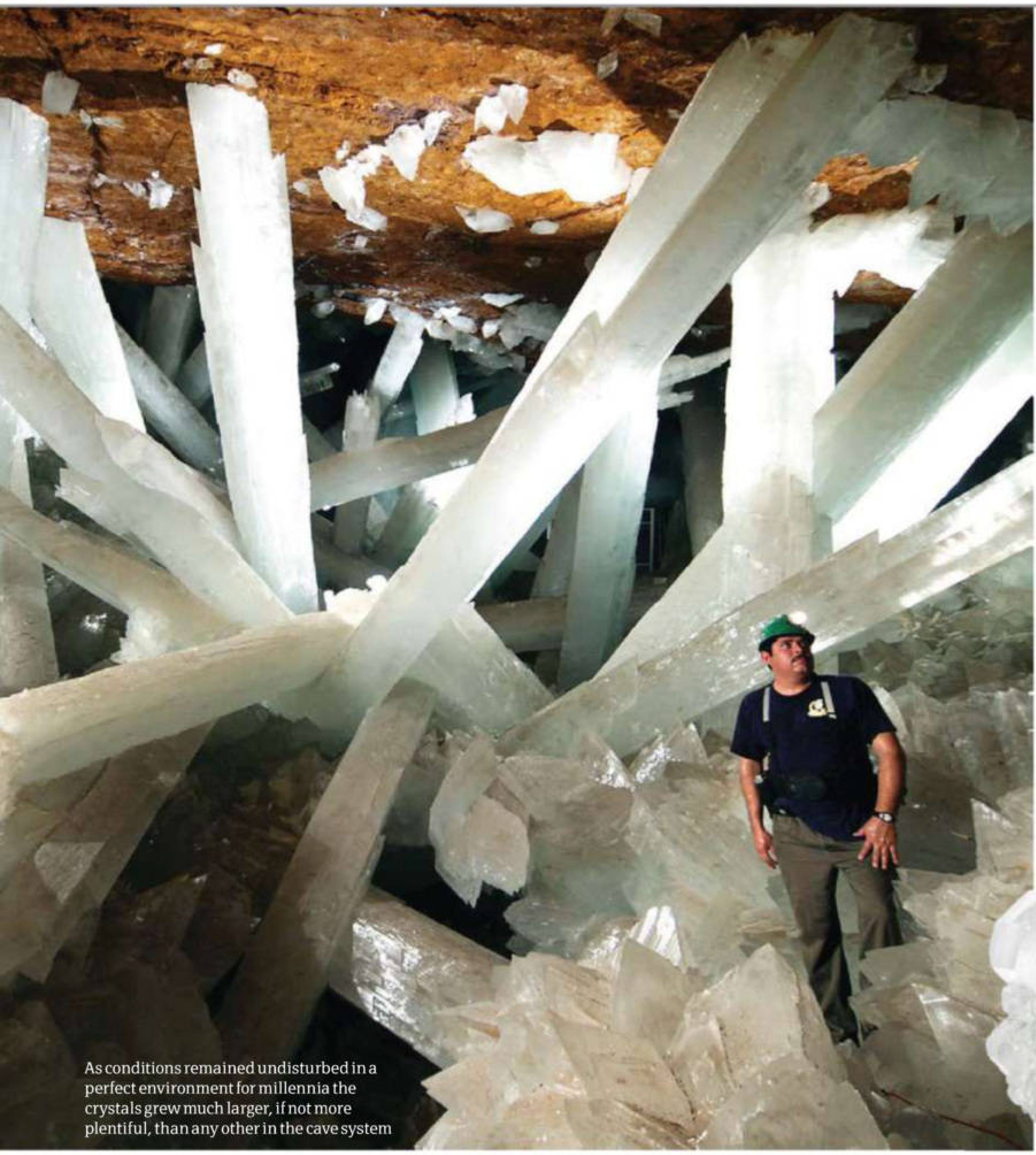
Geodes

Geodes look like ugly egg-shaped rocks, but inside are completely constructed with crystals. They take millions of years to form and are commonly created when a magma bubble cools. Dissolved minerals from flowing water etc, seep into this hard shell and attach to the inner wall. Through assisted nucleation, the crystal grows towards the centre. Quartz is the most common crystal to find in this way, but amethyst and other minerals can also be discovered.



As conditions remained undisturbed in a perfect environment for millennia the crystals grew much larger, if not more plentiful, than any other in the cave system

Cave of Crystals

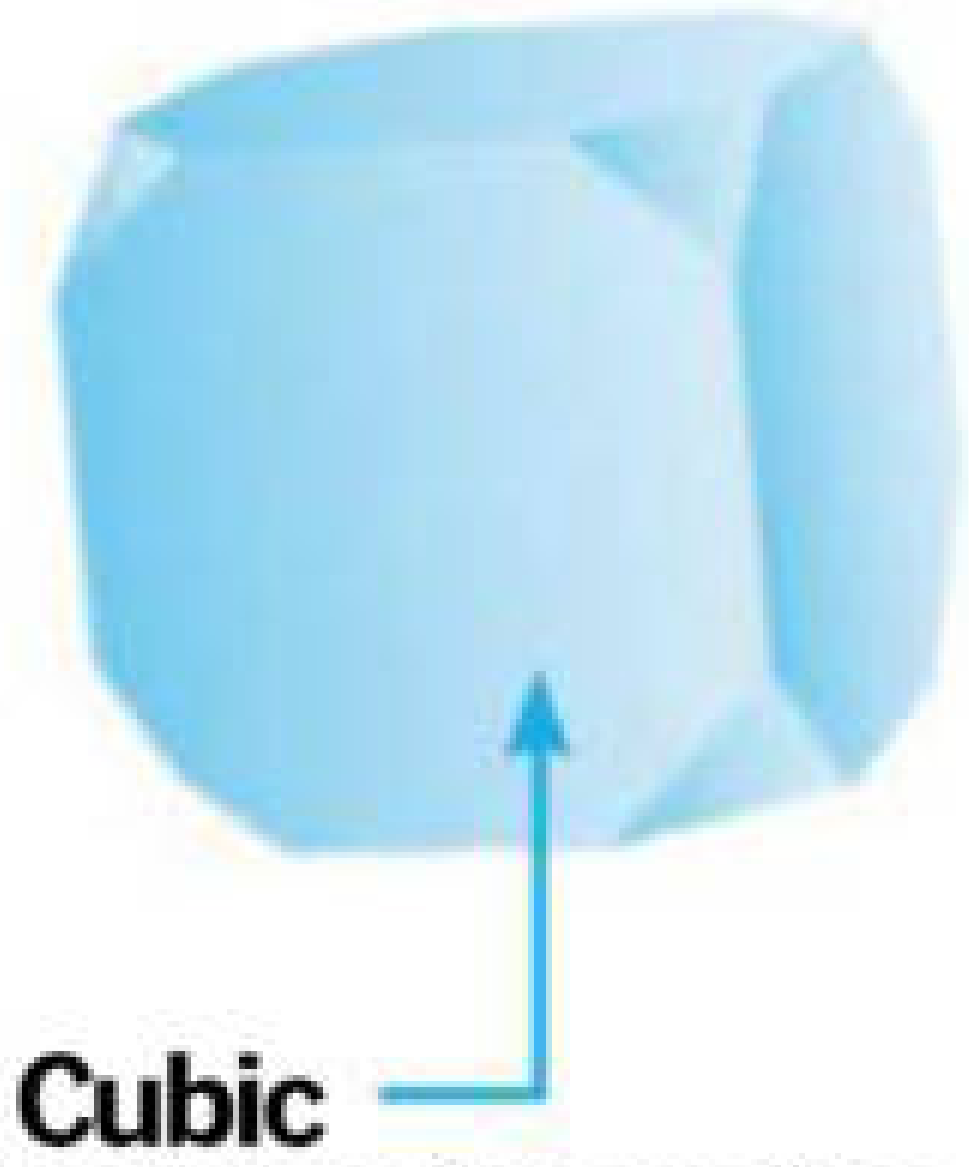
The Naica Mine of Chihuahua, Mexico, is a working mine that has become famous for its enormous crystals. 120m below the surface dwells the Cueva de las Espadas (Cave of Swords), discovered in 1912, and so-called because of its metre-long shafts of gypsum. However, the once-amazing find has now been eclipsed by a recent discovery that lies beneath the Cave of Swords: Cueva de los Cristales (Cave of Crystals) where gigantic 11-metre long crystals have been found.

It is believed that the huge beams formed in the 290-metre deep cave owe their size and statue to the fact that they've been allowed to form over hundreds of thousands of years in a very narrow, stable temperature range. It is believed that they were originally created as calcium sulphate found within groundwater filtered down through the caves. Magma from underneath the caves heated the water to a stabilised temperature of around 57°C, at which point the minerals converted to selenite molecules, which clustered over time to form crystals.

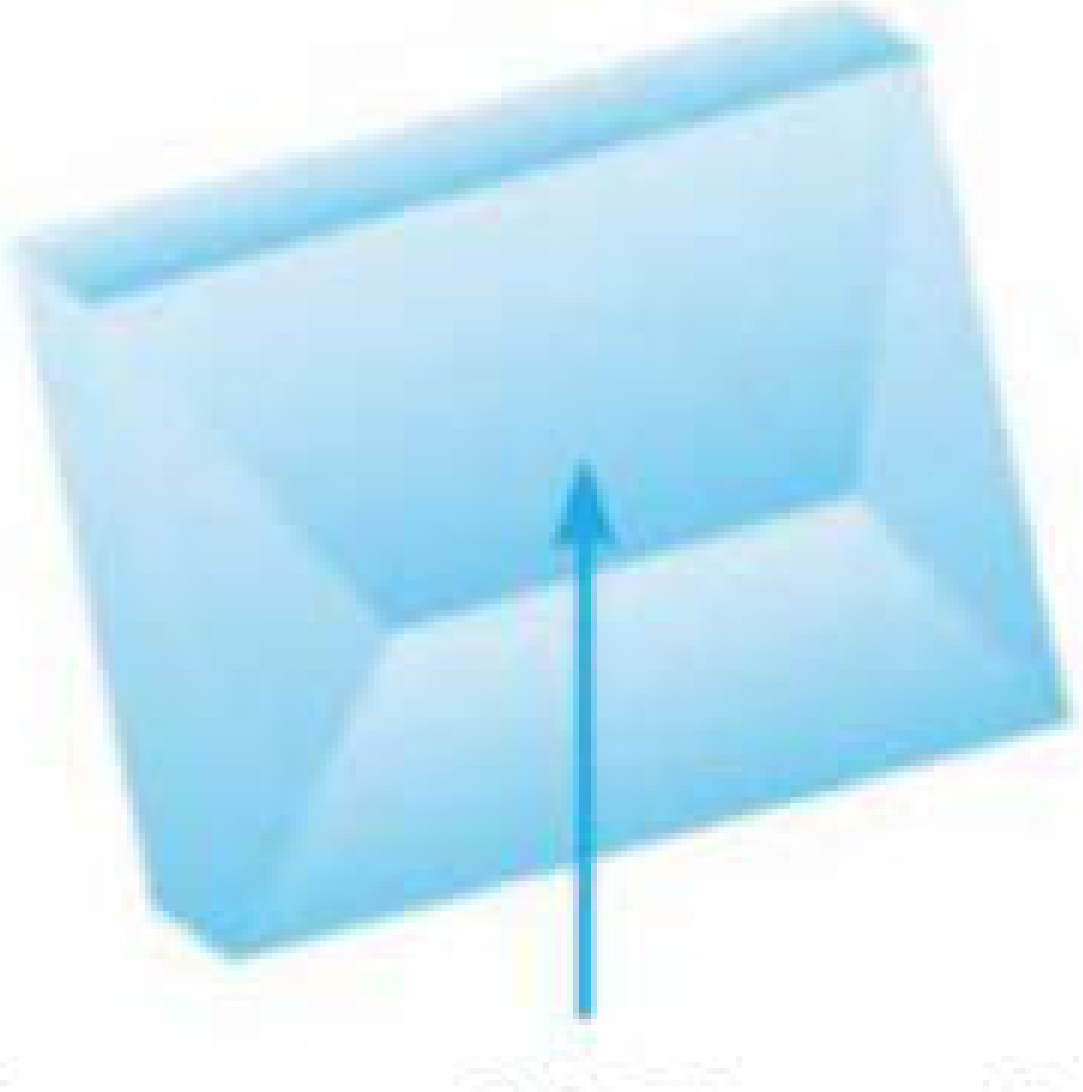
© Rob Lavinsky

Crystal systems

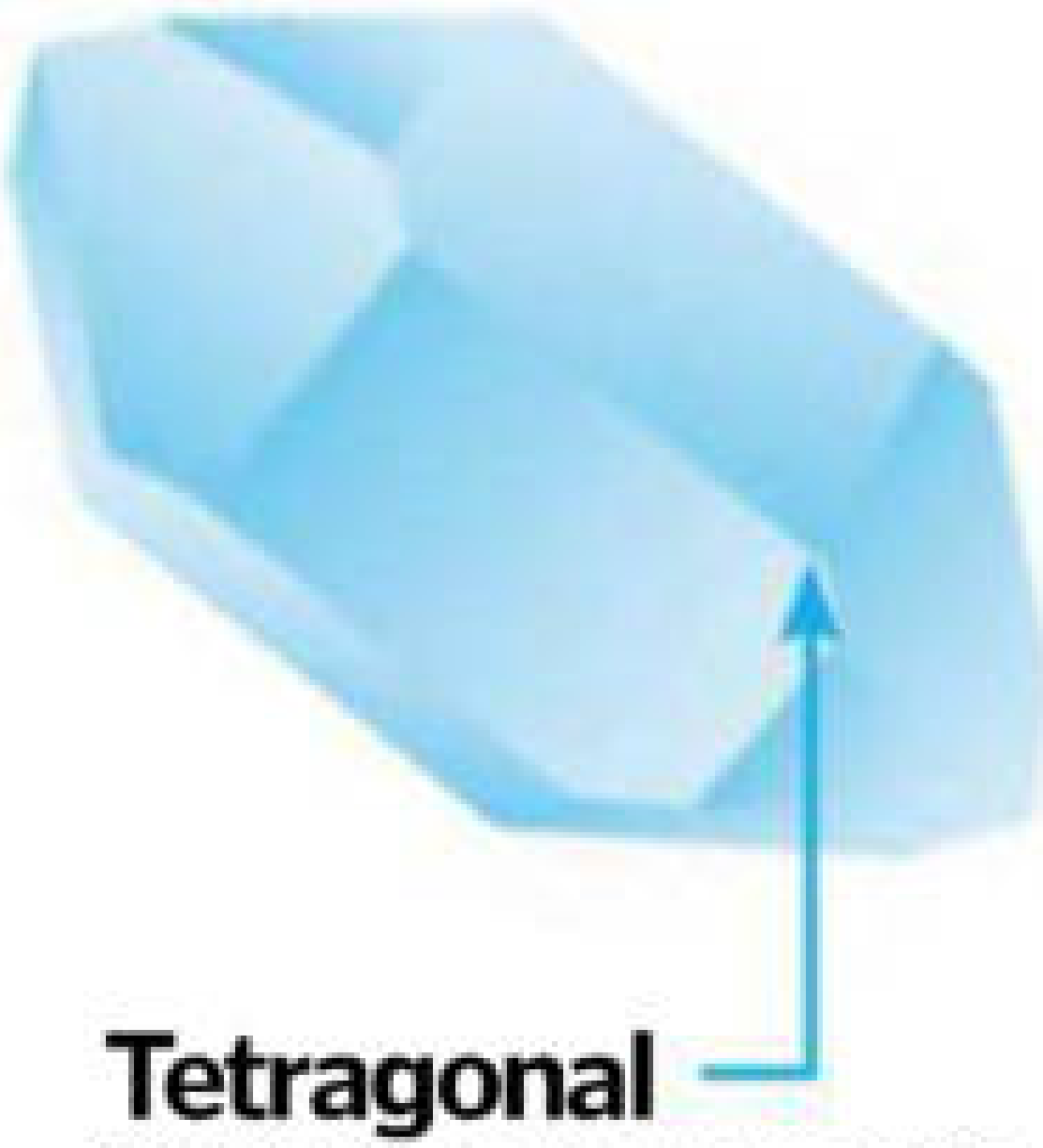
A free-growing crystal always forms a geometric shape with flat faces and all crystals form one of six systems of symmetry which help identify them...



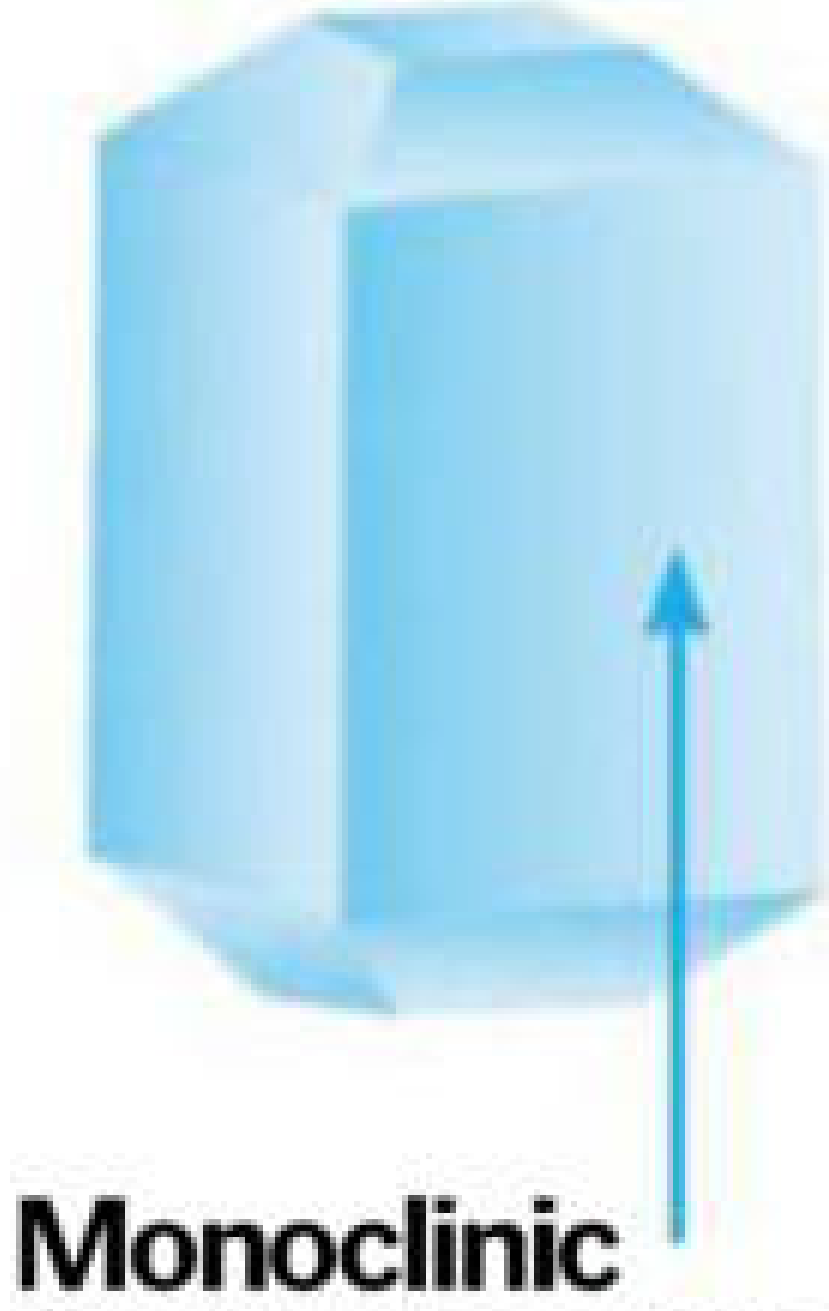
Cubic
Featuring eight or 12 sides these formations are not always square in shape.



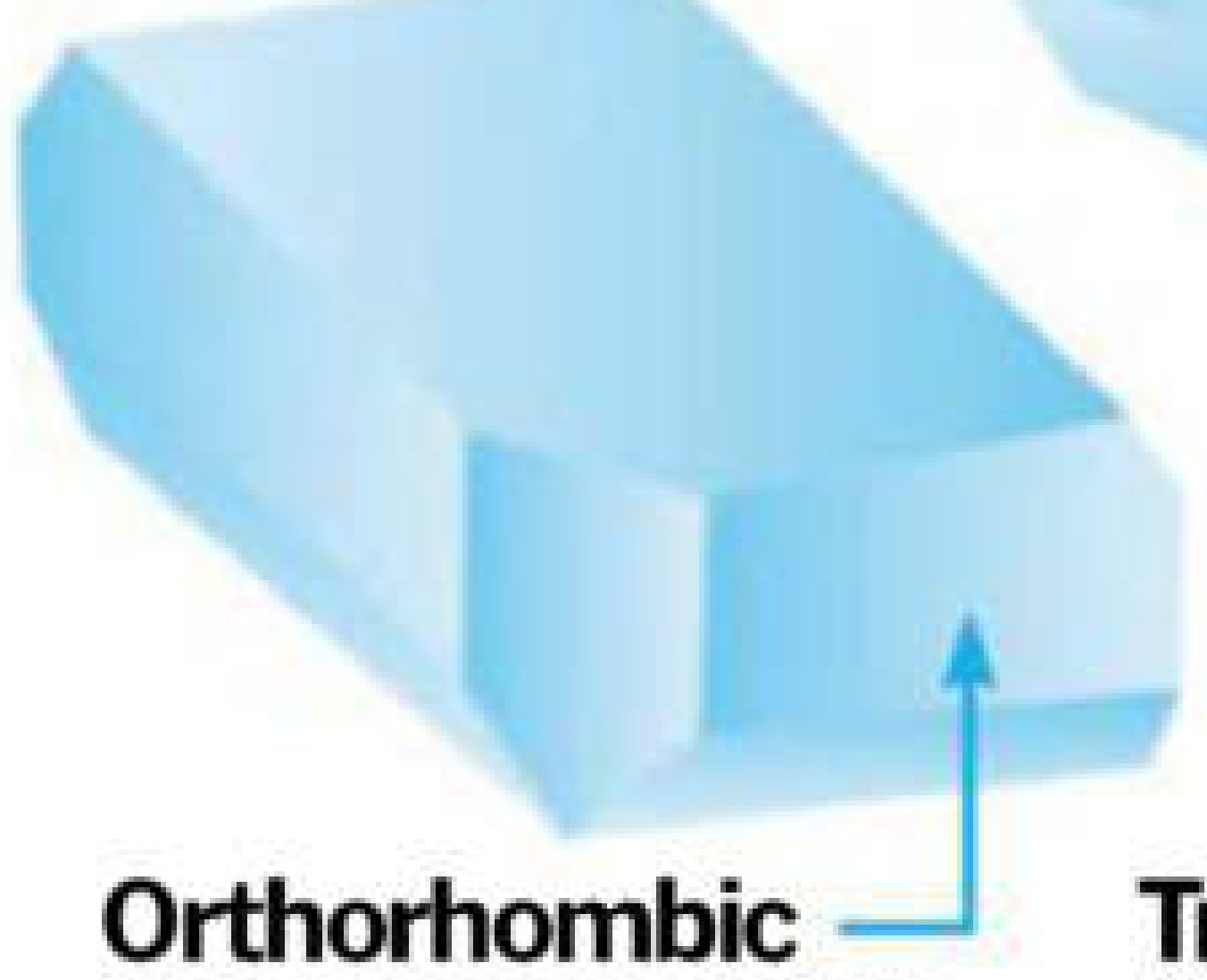
Hexagonal/ Trigonal
Hexagonal crystals are six-sided prisms, whereas trigonal ones have three or quasi-six sides.



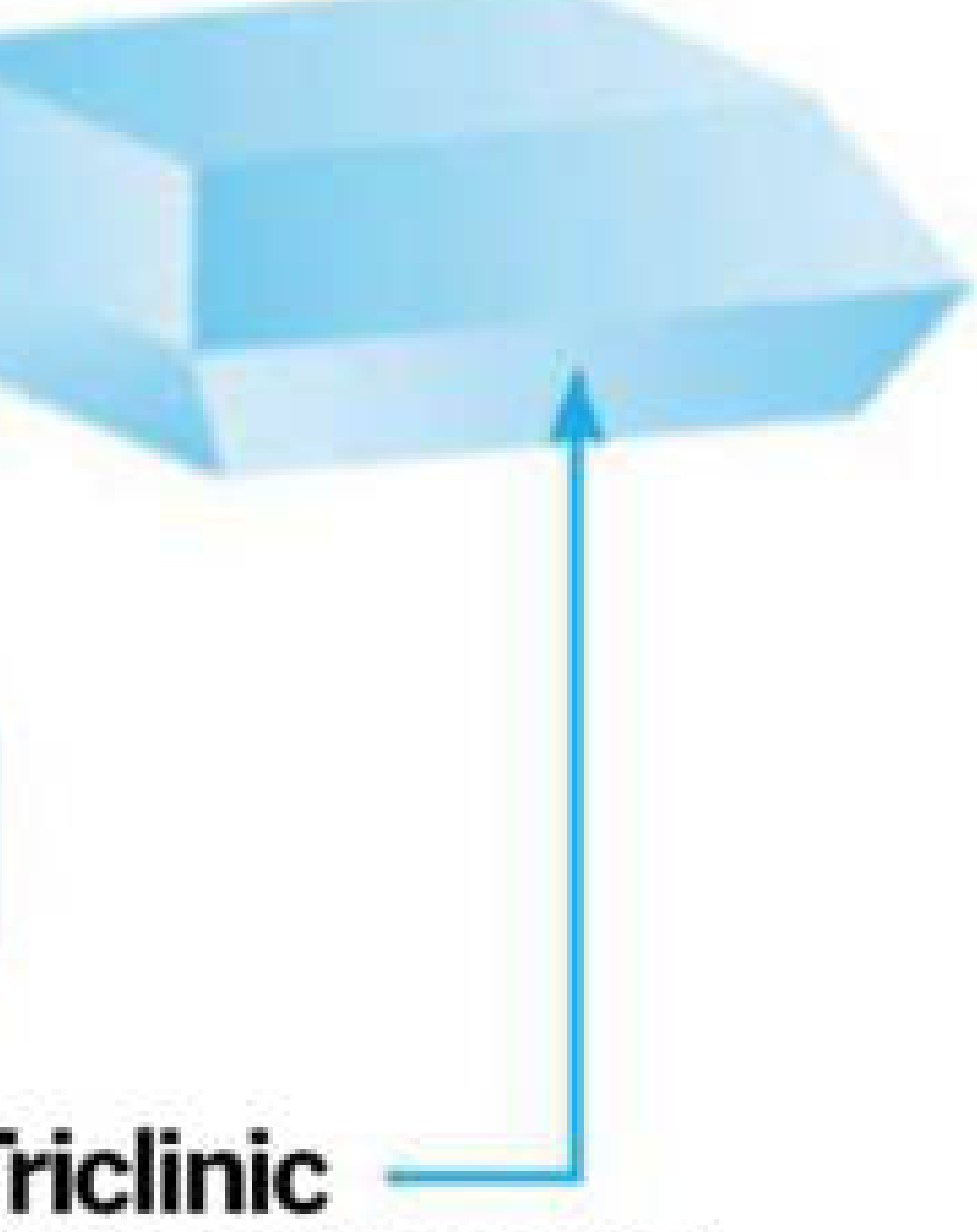
Tetragonal
Similar in makeup to cubic formations but longer along one axis that the other.



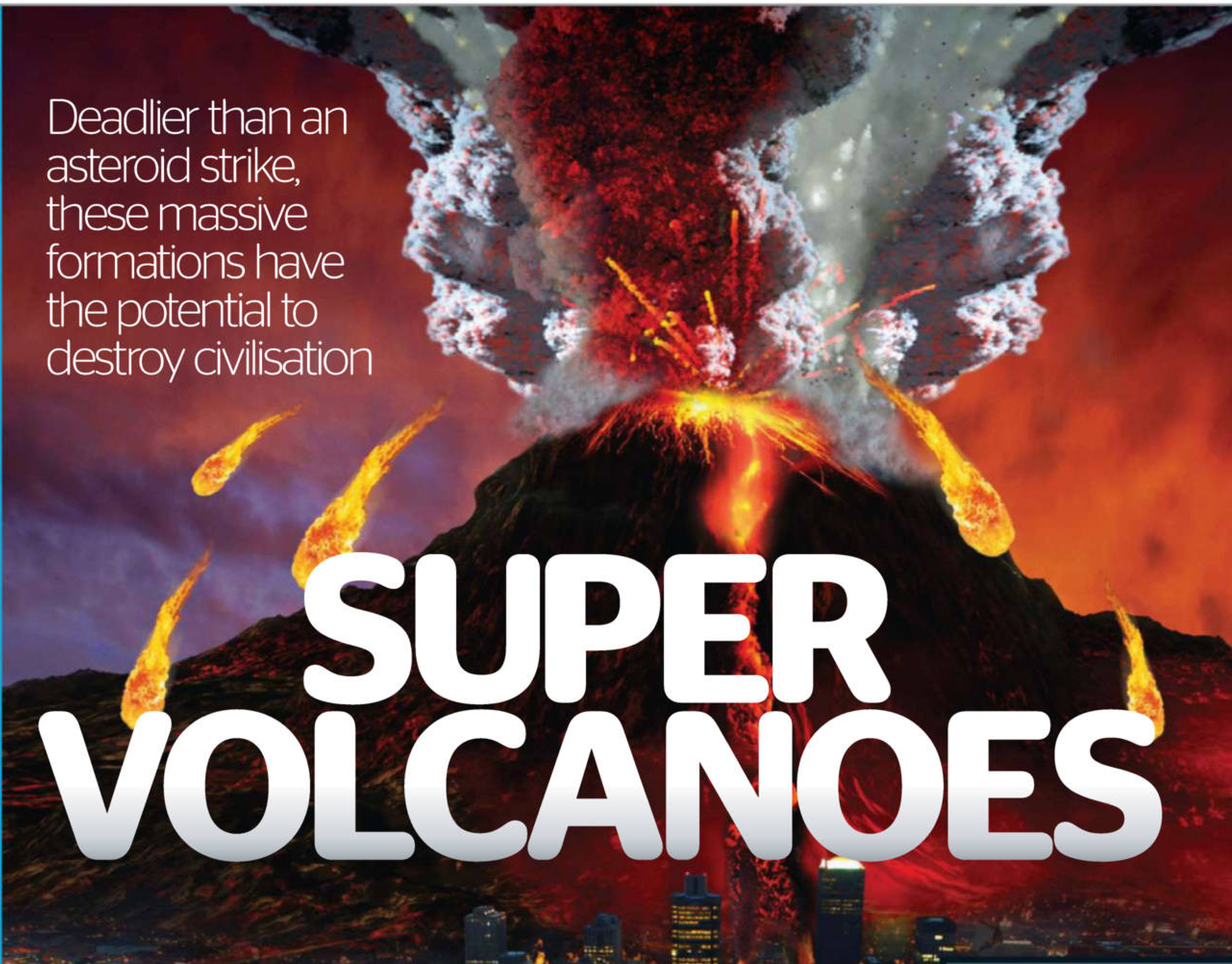
Monoclinic
Often forming a prism shape, these are often referred to as skewed tetragonal crystals.



Orthorhombic
These are not square in the cross section and instead form rhombic prisms.



Triclinic
Often sporting peculiar shapes, it's unsymmetrical on each side.



Deadlier than an asteroid strike, these massive formations have the potential to destroy civilisation

SUPER VOLCANOES

Many people will remember the airport chaos of spring 2010 when Eyjafjallajökull, one of Iceland's largest volcanoes, erupted after almost two centuries of slumber.

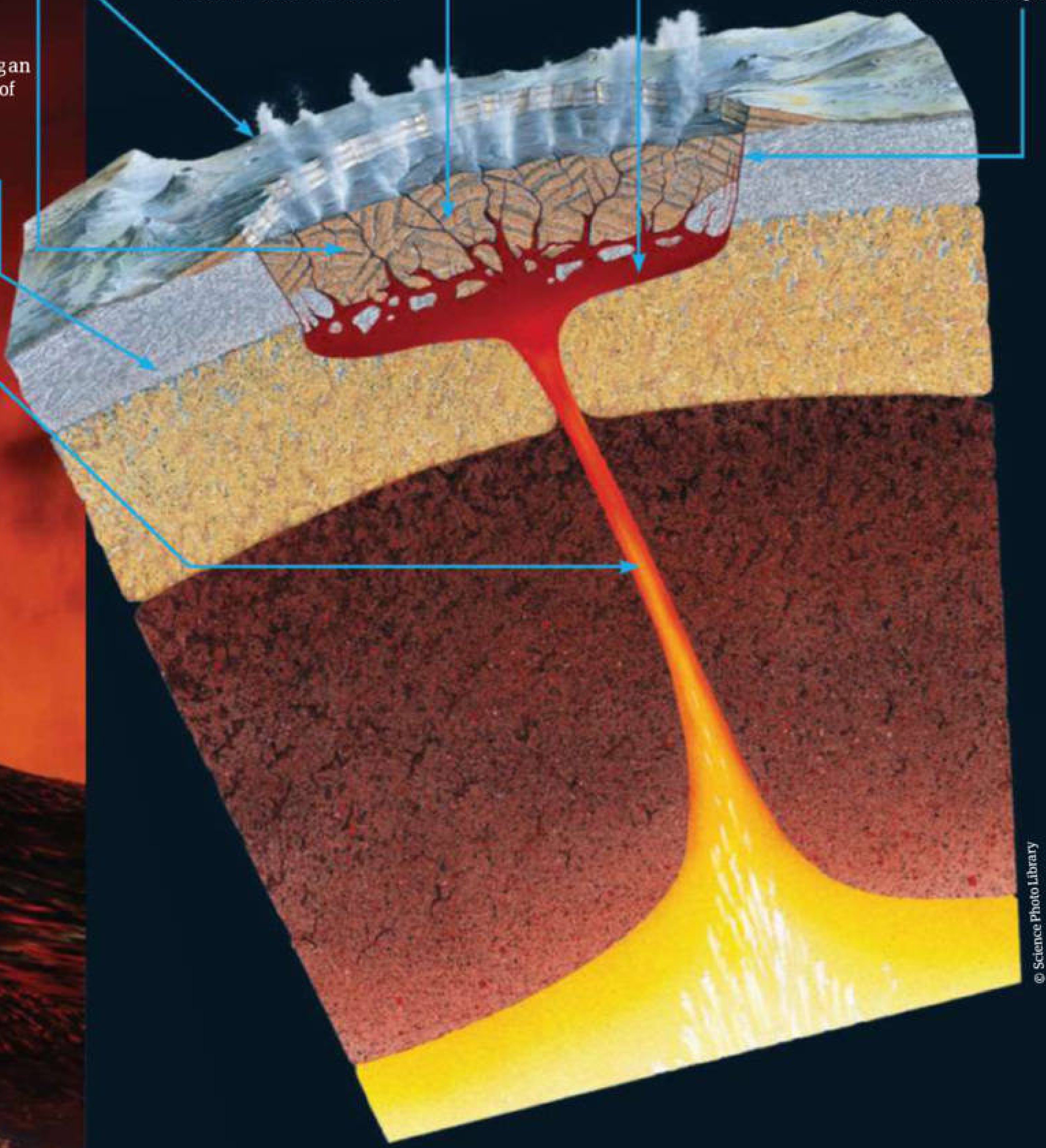
But though it might be hard to believe, considering the mammoth amount of disruption that it caused, the Icelandic eruption was tiny compared to a super-eruption's devastating power. The Eyjafjallajökull event measured a mere 4 on the Volcanic Explosivity Index (VEI), which rates the power of eruptions on an eight-point scale. A massive VEI 8 blast, on the other hand, would threaten human civilisation. Such a super-eruption would spew out more than 1,000 cubic kilometres (240 cubic miles) of ejecta – ash, gas and pumice – within days, destroying food crops, and changing the world climate for years.

A super-eruption hasn't happened in recorded history, but they occur about every 10,000-100,000 years. That's five times more often than an asteroid collision big enough to threaten humanity. Scientists say there's no evidence that a super-eruption is imminent, but humans will face nature's ultimate geological catastrophe one day.

A supervolcano is simply a volcano that's had one or more super-eruptions in its lifetime. Supervolcanoes are typically active for millions of years, but wait tens of thousands of years between major eruptions. The longer that they remain dormant, the bigger

The Okmok Caldera on Umnak Island in Alaska is 9.3km (5.8mi) wide

Inside a supervolcano



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Hot springs
Snow and rain seep down through fractures in the Earth's crust and are superheated by magma close to the surface.

Caldera
This cauldron-shaped hollow forms when a supervolcano's magma chamber empties during an eruption and the rock roof above collapses.

Earth's crust
The Earth's crust is perhaps 56 kilometres (35 miles) thick under the continents and made of solid rock.

Magma
Magma is lighter than the Earth's crust and rises towards the surface where it erupts as a volcano.

Resurgent dome
Molten rock rising in the underground magma chamber pushes the overlying caldera floor upwards into a dome.

Shallow magma chamber
An underground pool of molten rock called magma, which vents to the surface as a volcanic eruption.

Ring fractures
A circular fracture running around the collapsed edge of the magma chamber through which lava often escapes.

Predicting the next super-eruption

Volcanologists at the Yellowstone Volcanic Observatory are among those studying supervolcanoes. They hope to have decades or centuries to prepare for a super-eruption. Warning signs could include the ground bulging and cracking as hot rock muscles to the surface, an increase in small eruptions and earthquakes, and changes in the gases escaping the ground.

Scientists analyse earthquakes by measuring ground vibration with seismometers. Earthquakes often increase before eruptions as magma and gas force through underground fractures, causing rocks to break. The ground historically rises before eruptions due to upwelling magma. For example, the north flank of US volcano Mount St Helens rose by a staggering 80 metres (262 feet) in 1980.

Scientists constantly keep track of Earth movements using networks of satellite GPS receivers. Like GPS in cars, these monitor the receiver's location on the ground. Another satellite technology, InSAR, measures ground movement over large areas once or twice annually.

COUNTDOWN TO ERUPTION

1. MAGMA RISES
TIME: MILLIONS OF YEARS
Magma forms when rock deep in the Earth liquefies and pushes through the solid crust towards the surface.

2. PRESSURE BUILDS
TENS OF THOUSANDS OF YEARS
As magma accumulates in a chamber, the pressure builds and the cavity expands. Fractures begin to form in the chamber roof.

3. MAGMA CHAMBER EXPANDS
TENS OF THOUSANDS OF YEARS
Supervolcano magma chambers can grow for tens of thousands of years because they are surrounded by flexible hot rock.

4. WARNING SIGNS INCREASE
WEEKS TO CENTURIES
Warning signs of a super-eruption may include swarms of earthquakes and the ground rapidly swelling up like baking bread.

5. MAGMA CHAMBER RUPTURES
HOURS TO DAYS
Vertical fractures in the swollen crust breach the magma chamber, allowing pressurised, gas-filled magma to escape to the surface as lava.

6. SUPER-ERUPTION
HOURS TO DAYS
The expanding gases act like bubbles of pop in a shaken bottle, flinging lava and rock high into the atmosphere.

7. DEADLY CLOUDS
DAYS
The fractures join into a ring of erupting vents. Toxic ash and fragment clouds race downhill at snow avalanche speed.

8. CALDERA FORMS
DAYS
The rock cylinder inside the ring fractures and plunges into the emptied magma chamber. Gas and lava spurt from the fractures.

This artist's illustration reveals the clouds of smoke and ash that could result from a supervolcanic eruption at Yellowstone

© Science Photo Library

The fallout following a super-eruption

A supervolcano erupting today could threaten human civilisation. Clouds of molten rock and iridescent gas travelling three times faster than motorway cars would obliterate everything within 100 kilometres (60 miles) of the blast. Dust would spread thousands of kilometres, blotting out the Sun. People's unprotected eyes, ears and noses would fill with needle-like ash, which can pop blood vessels in the lungs and kill by suffocation.

Up to 0.5 metres (1.6 feet) of ash could rain down each hour, collapsing roofs, poisoning water supplies and halting transport by clogging car and aircraft engines; just a few centimetres of ash can disrupt agriculture. The 1815 eruption of Indonesia's Mount Tambora caused the 'year without a summer' when European harvests failed, bringing famine and economic collapse. Financial markets could be disrupted and countries swamped by refugees. Some scientists say a Yellowstone super-eruption could render one-third of the United States uninhabitable for up to two years.

▶ the super-eruption. They typically erupt from a wide, cauldron-shaped hollow which is known as a caldera, although not every caldera houses a future supervolcano.

The supervolcano simmering under Yellowstone National Park in the USA is probably the world's most studied supervolcano, but super-eruptions occur so rarely that they remain a mystery. We know of 42 VEI 7 and VEI 8 eruptions in the last 36 million years, but much debris from ancient super-eruptions has worn away. Eruptions like these take place at irregular intervals and scientists are unsure what triggers them.

Supervolcanoes, like all volcanoes, occur where molten or partly molten rock called magma forms and erupts to the Earth's surface. All supervolcanoes break through the thick crust that forms the continents. The Yellowstone caldera sits on a hot spot, a plume of unusually hot rock in the solid layer called the mantle that lies below the Earth's crust. Blobs of molten mantle rise from the hot spot towards the surface and melt the crustal rocks.

Other supervolcanoes like Lake Toba in Sumatra, Indonesia, lie on the edges of the jigsaw of plates that make up the Earth's crust. Near Sumatra, the plate carrying the Indian Ocean is being pushed underneath the crustal plate carrying Europe. As it descends, the ocean plate melts to form magma.

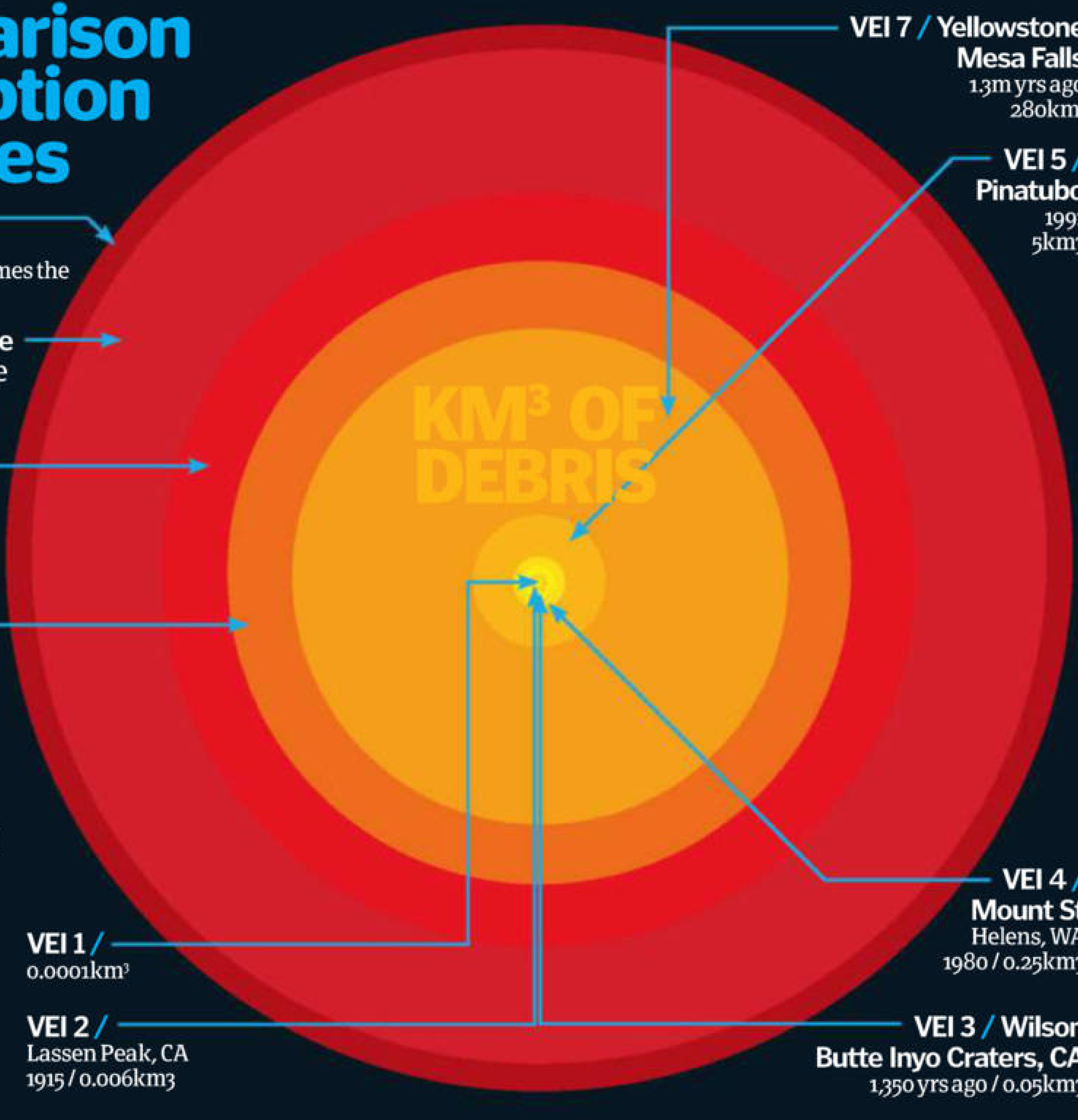
Vast quantities of magma are needed to fuel a super-eruption. Some scientists believe that supervolcanoes are 'super' because they have gigantic, shallow magma chambers that can hold volumes of up to 15,000 cubic kilometres (3,600 cubic miles) and grow for thousands of years. Magma chambers are underground pools of accumulated magma that erupt through cracks to the surface. Volcanoes with smaller chambers expel magma before enough pressure builds for a supersized event.

Some scientists speculate that hot and flexible rocks surround supervolcano magma chambers, allowing them to swell to accommodate more magma. The rocks are kept malleable by blobs of magma repeatedly welling up from below.

A super-eruption starts when the pressurised magma explodes through fractures in the chamber roof. The eruption is violent because supervolcano magma is rich in trapped gas bubbles, which expand and burst as it abruptly depressurises; the eruption is akin to uncorking a champagne bottle. The magma is also sticky and unable to flow easily because it's made partly from melted continental crust. This is in contrast to a volcano like Mauna Loa in Hawaii, which gently pours out lava because its magma is fluid and contains little gas.

Hot fragments and gas soar to heights of more than 35 kilometres (22 miles) and spread in the atmosphere. Some of the fragments drift down and blanket the ground like snow. Other hot fragments rush downhill for hundreds of square kilometres at speeds exceeding 100 kilometres per hour (62 miles per hour) as toxic, ground-hugging pyroclastic flows. The magma chamber rapidly drains during the super-eruption, causing the roof above to sink into the empty space to (re-)form a caldera. ✺

Comparison of eruption volumes



VEI 8 / Toba
74,000 yrs ago
2,800km^3 (that's 380 times the volume of Loch Ness)

VEI 8 / Yellowstone
Huckleberry Ridge
2.1m yrs ago
2,450km^3

VEI 8 / Yellowstone
Lava Creek
640,000 yrs ago
1,000km^3

VEI 7 / Long Valley Caldera
760,000 yrs ago
580km^3

VEI 7 / Yellowstone Mesa Falls
1.3m yrs ago
280km^3

VEI 5 / Pinatubo
1991
5km3

VEI 4 / Mount St
Helens, WA
1980 / 0.25km3

VEI 3 / Wilson Butte Inyo Craters, CA
1,350 yrs ago / 0.05km3

VEI 2 /
Lassen Peak, CA
1915 / 0.006km3

VEI 1 /
0.0001km^3

Volcanic Explosivity Index (VEI)

Volume of material in eruption

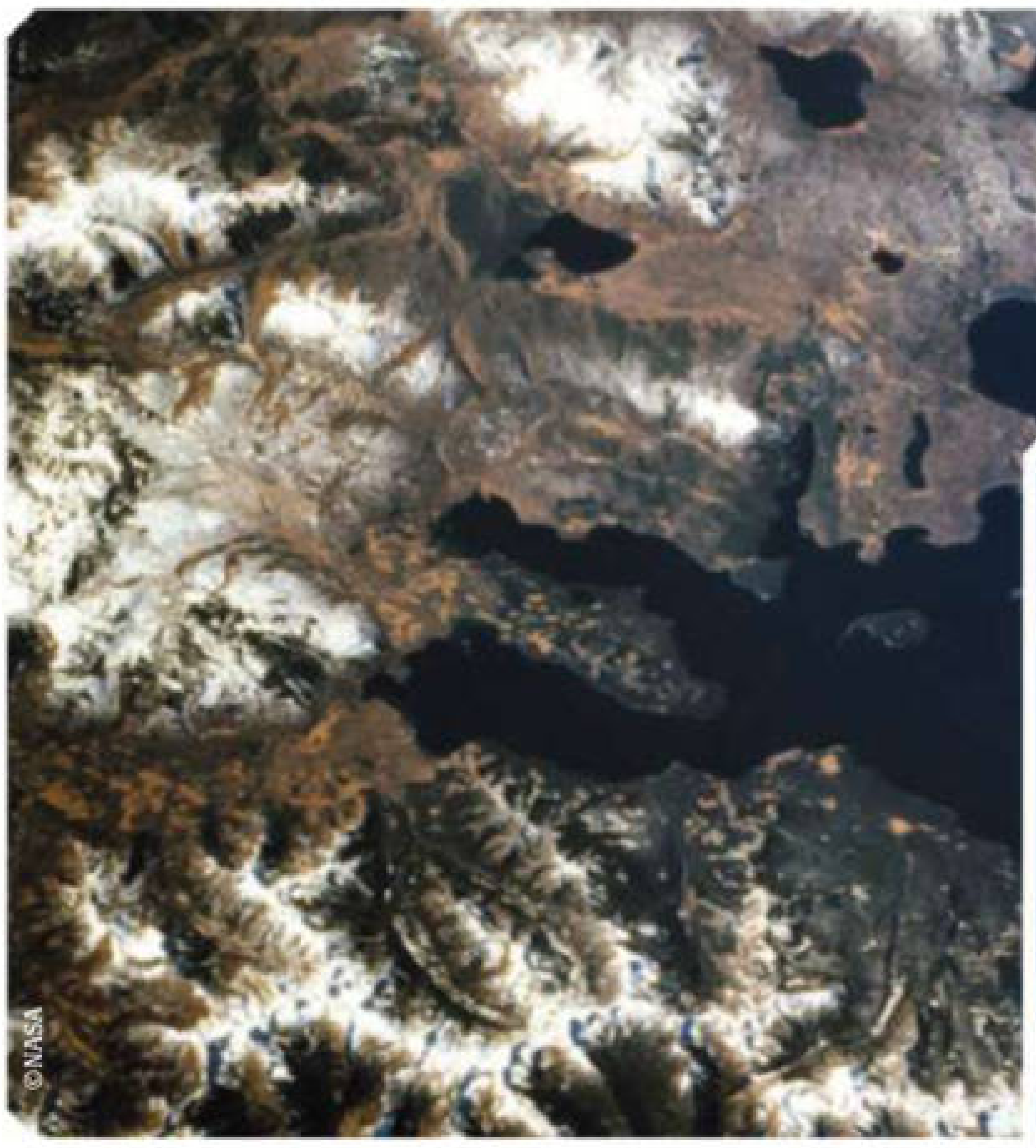
VEI 8: >1,000km^3
VEI 7: 100-1,000km^3
VEI 6: 10-100km^3
VEI 5: 1-10km^3
VEI 4: 0.1-1km^3
VEI 3: 0.01-0.1km^3
VEI 2: 0.001-0.01km^3
VEI 1: 0.00001-0.001km^3
VEI 0: <0.00001km^3

VOLCANOES VS SUPERVOLCANOES

The explosive battle

	TYPICAL VOLCANO	TYPICAL SUPERVOLCANO
FOOTPRINT	Volcanoes vary, but a typical shield volcano might be 5.6km (3.5mi) across. The crater – like a caldera – of Mount St Helens, USA, is about 3.2km (2mi) wide.	Bigger calderas produce larger eruptions, meaning most supervolcanoes cover vast areas. Lake Toba is 90km (56mi) long and lies in such a caldera.
HEIGHT	Normal volcanoes are cone-shaped mountains perhaps 1km (3,280ft) high. Mount St Helens, for example, stands 635m (2,084ft) above its crater floor.	Supervolcanoes have 'negative' topography: they erupt from smouldering pits. Lake Toba lies in a supervolcano caldera and is over 0.5km (0.3mi) deep.
VOLUME	Typical volcanoes have smaller magma chambers. The magma chamber of Mount St Helens, for example, has a volume of just 10-20km^3 (2.4-4.8mi^3).	Yellowstone's magma chamber and caldera are similar in width. The chamber is 60 x 40km (37 x 25mi) wide, and 5-16km (3-10mi) below the surface.
EJECTA	Even huge volcanoes produce comparatively little debris; eg Yellowstone's super-eruptions were up to 2,500 times bigger than the 1980 St Helens blast.	Super-eruptions eject more than 1,000km^3 (240mi^3) of debris. They also spew at least 10^{15}kg (10^{12} tons) of magma: more than the mass of 50 billion cars.
DAMAGE	A few eruptions, like Mt Tambora in 1815, changed global climate, but most of the 20 volcanoes erupting as you read this affect only their immediate vicinity.	A Yellowstone eruption could drop the global temperature up to 10°C (50°F) for ten years. Within 1,000km (621mi) of the blast, 90 per cent of people could die.

A super-eruption took place in Sumatra 74,000 years ago, forming the planet's largest volcanic lake in the process: Lake Toba



A satellite view of Yellowstone National Park, which is positioned above a hot spot in the Earth's crust

©NASA

Geysers like Old Faithful at Yellowstone are heated by the supervolcano which lies beneath

Yellowstone's restless giant

Beneath Yellowstone National Park bubbles an active supervolcano. A magma chamber, lying as close as eight kilometres (five miles) to the surface in places, fuels the park's 10,000 jewel-coloured hot springs, gurgling mud pools, hissing steam vents and famous geysers like Old Faithful. The 8,897-square-kilometre (3,435-square-mile) park includes the volcano's caldera, which spans 4,400 square kilometres (1,750 square miles); that's big enough to cover the emirate of Dubai.

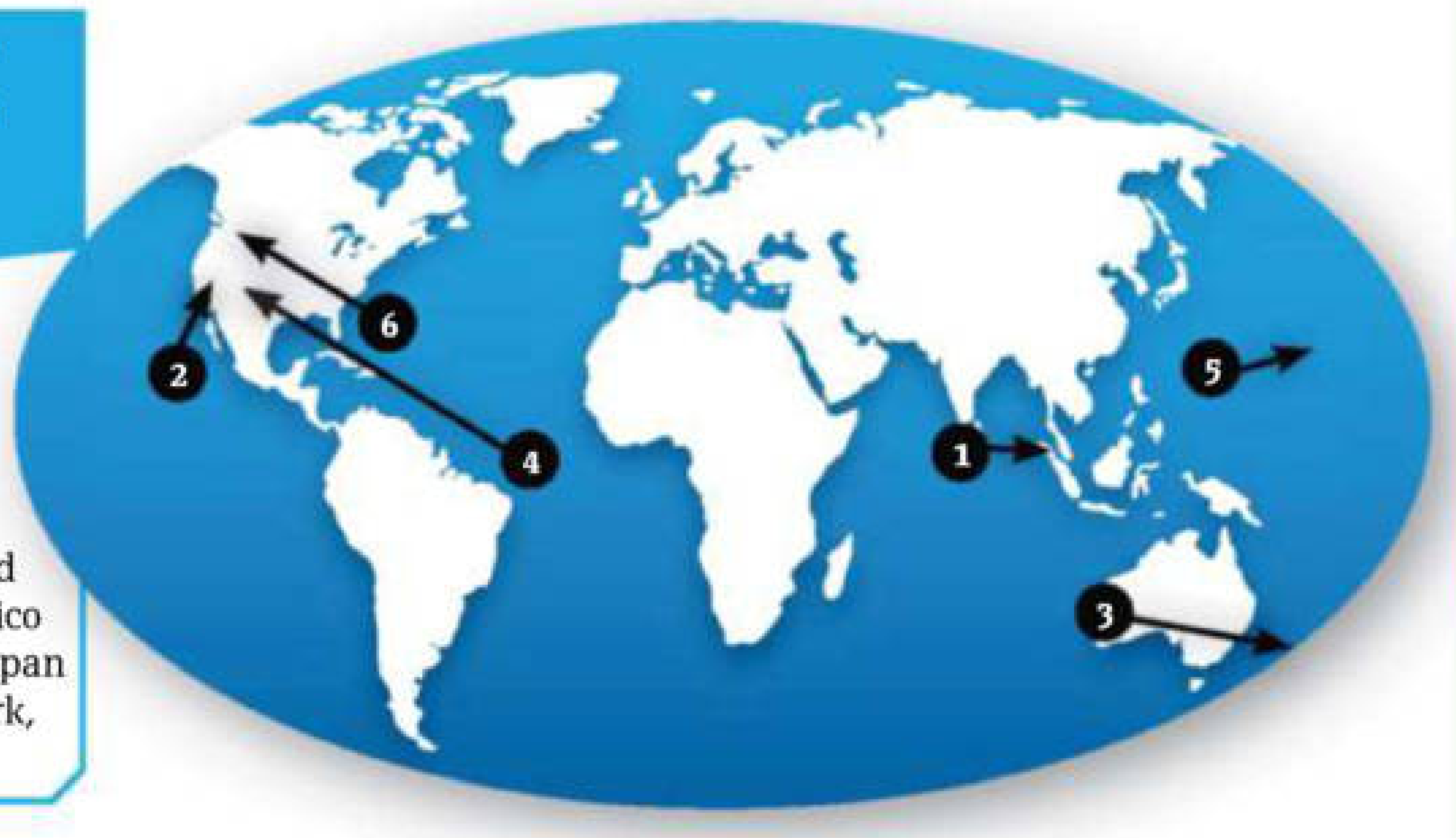
The supervolcano is fuelled by a 'hot spot', a plume of hot rock rising from hundreds of kilometres below the Earth's surface. Hot spots act like huge Bunsen burners, driving catastrophic eruptions by melting the rocks above them. Scientists are uncertain why hot spots form; they're not found at the edge of Earth's crustal plates and most volcanic activity happens where these plates jostle against one another. Since the hot spot formed around 17 million years ago, it has produced perhaps 140 eruptions. The North American crustal plate has slid southwest over the stationary hot spot like a conveyor belt, leaving a 560-kilometre (350-mile) string of dead calderas and ancient lava flows.

There have been three super-eruptions since Yellowstone moved over the hot spot: 2.1 million, 1.3 million and 640,000 years ago. Each eruption vented enough magma from the volcano's storage reservoir to collapse the ground above into a caldera. The first and largest eruption created the Huckleberry Ridge Tuff, more than 2,450 cubic kilometres (588 cubic miles) of volcanic rock made of compacted ash. The eruption blasted a huge caldera perhaps 80 x 65 kilometres (50 x 40 miles) in area and hundreds of metres deep across the boundary of today's national park. The most recent eruption blanketed much of North America in ash and formed Yellowstone Caldera. Hot gas and ash swept across 7,770 square kilometres (3,000 square miles).

ON THE MAP

Six known supervolcanoes

1 Lake Toba, Sumatra, Indonesia
2 Long Valley, California
3 Lake Taupo, New Zealand
4 Valles Caldera, New Mexico
5 Aira Caldera, southern Japan
6 Yellowstone National Park, United States



Amazing

138 **The planet's deadliest animals**
A selection of the scariest creatures on the face of the Earth

144 **Deadly dinosaurs**
Who was king of the dinosaurs?

148 **The life of frogs**
A look at this incredible amphibian

150 **Frog leaps**
Find out how frogs hop so far

151 **Super-snappy tongues**
Hunting with projectile tongues

152 **Crocodile jaw**
What makes their bite so strong, and how can an elastic band stop it?

152 **Amphibian skin**
Underneath an amphibian's surface

153 **Death rolls**
A deadly skill used by feeding crocodiles

153 **Why do snakes shed skin?**
Explaining why snakes moult so often

153 **How do snakes bite?**
How these killers have adapted

154 **How whales communicate**
Explore how whales make sounds

154 **Venomous fish**
Meet the world's deadliest fish

155 **Dog noses**
How a dog's super-sniff works

155 **Vampire bats**
Why their fangs help them survive

156 **Underwater wonders**
Nature's raft of marine beasts

160 **Emperor penguins**
Life at the pole for these birds

162 **Giant pandas explained**
Why do they love bamboo so much?

164 **Hippo jaws**
Think you can open yours this wide?

165 **Hibernation explained**
The importance of sleep

How do ladybirds fly? p171

How do whales communicate? p154

What are ligers and tigons? p165

What do pandas eat? p162

animals

165 Ligers and tigons
What are these cross-breeds?

166 Flying squirrels
How these rodents can glide

167 Camel humps
The desert's own water bank

167 Kangaroos
Australia's biggest bounders

168 How do birds breathe?
An extremely efficient respiratory system that keeps birds alive

168 Earthworms
Can they really survive when cut in half, or is it a myth?

169 Beaver dams
Discover these incredible construction workers!

169 Bats' ultrasonic sonar system
How bats can hear so perfectly

170 Dragonflies
A look at these incredible creatures who can fly in any direction

170 Metamorphosis
The science behind transformation

171 Ladybirds explained
Beautiful but also talented, these little beetles are gardeners' friends

172 Tardigrades
These tough but tiny mini-beasts can survive the most inhospitable climes

172 Slugs and snails
Which one is the slimiest, and what goes on under a snail's shell?

173 Termite mounds
How big can these multi-storey termite towers really get?

174 Scorpions
The armoured arachnids with a nasty sting in their tail

Drug lord Pablo Escobar kept pet hippos on his Colombian ranch!

Komodo dragons taste the air to find their prey by flicking their tongues

Jellyfish stings fire with an acceleration of about 40,000 g!

Since the domestication of grey wolves thousands of years ago, selective breeding has made dogs more docile

The planet's deadliest animals

If you go down to the woods today... you may not come out alive!

We don't live in a dog-eat-dog world. It's much more dangerous than that. Dog-eat-dog suggests an evenly matched fight, but animals in the wild prefer to attack from a position of overwhelming superiority. A snake with a taste for mice can inject enough deadly venom to kill 125 mice with a single bite, while an animal that relies on physical strength will aim for an instant kill by crushing the skull or slicing the throat.

The prey is fighting for its life and will put up the maximum possible struggle, but the predator is only hunting for its dinner and cannot afford even minor injuries so it must strike hard and kill quickly.

Humans, however, are weak. Almost any animal our size could easily beat us in a fight. We protect ourselves by keeping away from most of nature and using technology to protect ourselves. Most of the time this works. But you can't spend your whole life in a shark cage and animals carry their weapons with them all the time. So when accidental wild encounters do occur, the fight isn't likely to go our way.

There are lots of ways to rate the deadliness of an animal. The total number of human fatalities every year is one, but it doesn't take into account how rare the animal is, or where it lives. Brown bears kill more people than polar bears do, but that doesn't make brown bears more deadly per se. It just means that a lot more people go hiking in Alaska than on the sea ice in the Arctic Circle. Official statistics can be misleading too. Shark attack figures tend to exaggerate the deaths from the easily identified species, such as the great white and the tiger shark and those that feed close to the shore, where there are likely to be lots of witnesses. As you will see, the shark species probably responsible for the most human deaths has almost no confirmed kills to its name, precisely because it never leaves any witnesses...

Where an animal is venomous, rating the deadliness of its venom is very tricky. Venom toxicity is measured using the LD50 rating. This is the dose of venom, in milligrams per kilogram of body weight, required to kill 50 per cent of the mice in a sample. Mice are used because they are a convenient laboratory animal which can stand in for humans. But mice are also common prey for many snakes, scorpions and lizards and so have evolved a high degree of immunity to the venom of several species. The predator adapts to this by

The polar bear is the largest land carnivore and its great size means it can overpower even large prey

75 per cent of attacks occur with cassowaries that have been fed by humans

According to the International Shark Attack Files, records of shark attacks on humans go back to the 16th Century

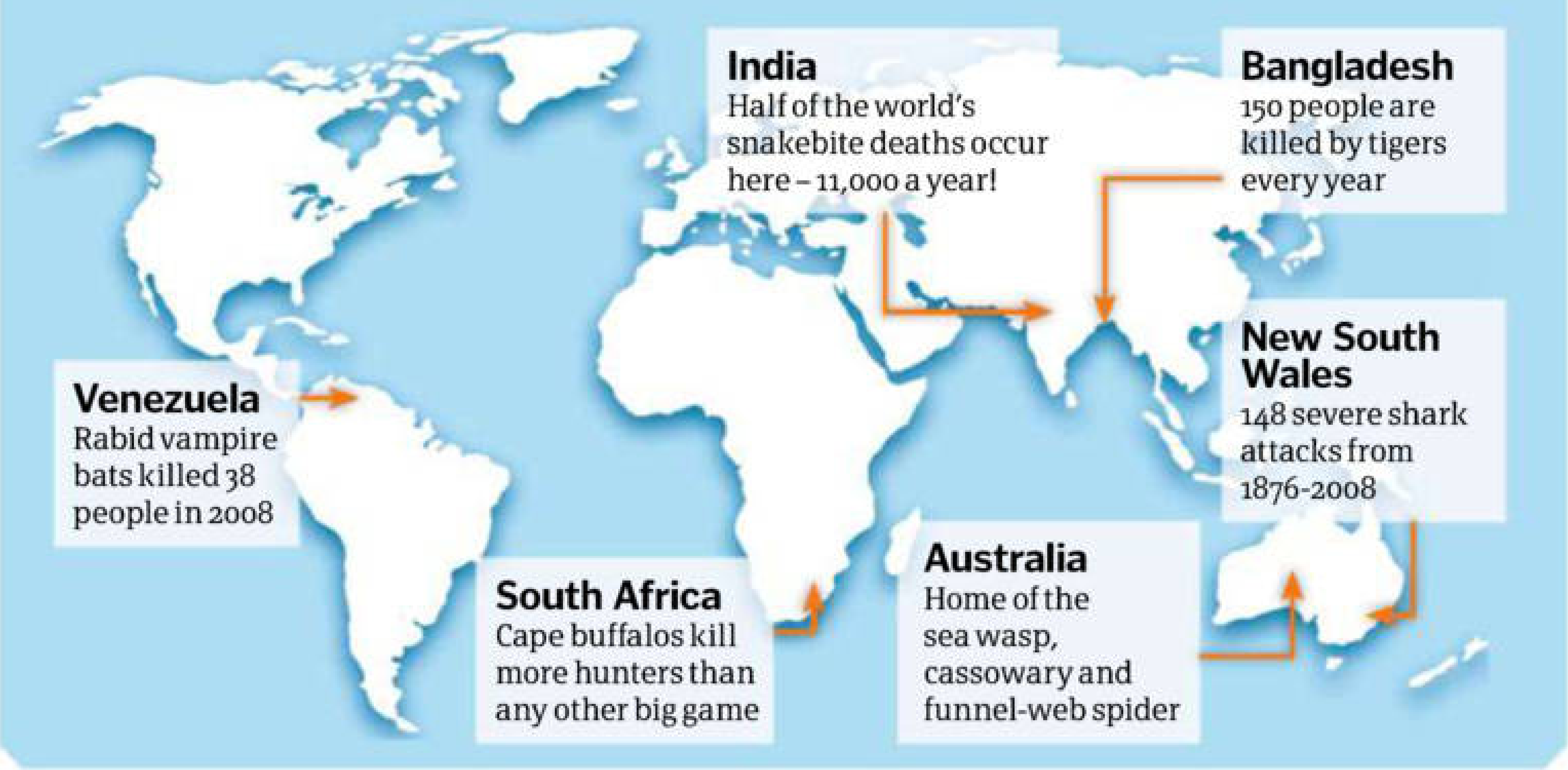
It takes 70 spider 'milkings' to make just one dose of antivenom

Black mambas are the world's fastest snakes, travelling at up to 19km/h (12mph)!
2
1

injecting ever-larger amounts of venom and this makes them even more dangerous to humans. So paradoxically, animals with low venom toxicity as measured by LD50 in mice, can be among the most lethal to humans.

The list we have compiled here contains ten of the very deadliest animals on the planet, covering as wide a range of different habitats and kill tactics as possible. Inevitably, we have had to leave out some very worthy runners-up. The Nile crocodile eats about 320 people a year and tigers have killed 373,000 people since the beginning of the 19th century. The cape buffalo is an extraordinarily aggressive animal that has probably killed more hunters than any other animal in Africa. But our list is a representative sample of the meanest killers from across the whole of Mother Nature's realm.

Hotspots for fatal animal attacks


India
Half of the world's snakebite deaths occur here – 11,000 a year!

Bangladesh
150 people are killed by tigers every year

New South Wales
148 severe shark attacks from 1876-2008

Venezuela
Rabid vampire bats killed 38 people in 2008

South Africa
Cape buffalos kill more hunters than any other big game

Australia
Home of the sea wasp, cassowary and funnel-web spider

SEA WASP JELLYFISH

The sting king

- **Size** 30cm (11.8in) body, 3m (9.8ft) tentacles
- **Habitat** Open water • **Location** Australasia
- **Diet** Prawns, small fish • **Kill tactic** Sting

The sea wasp is the largest and most deadly of the Cubozoa, or box jellyfish. In fact, it may be the most venomous creature in the world. Sea wasps hunt small fish and shrimp, but their delicate bodies make it essential for them to immobilise their prey immediately. Their venom works on humans by causing red blood cells to leak potassium molecules, disrupting the electrical signals that allow muscles to contract and so your heart stops beating. This works the same way as the lethal injection used for capital punishment. Large numbers of sea wasps can gather in shallow coastal waters at certain times of year and their bodies are virtually transparent, making it easy to blunder into one by accident. Victims often drown before reaching the shore, or die of heart failure soon after.

STING STATS

Average number of tentacles per sea wasp jellyfish
60

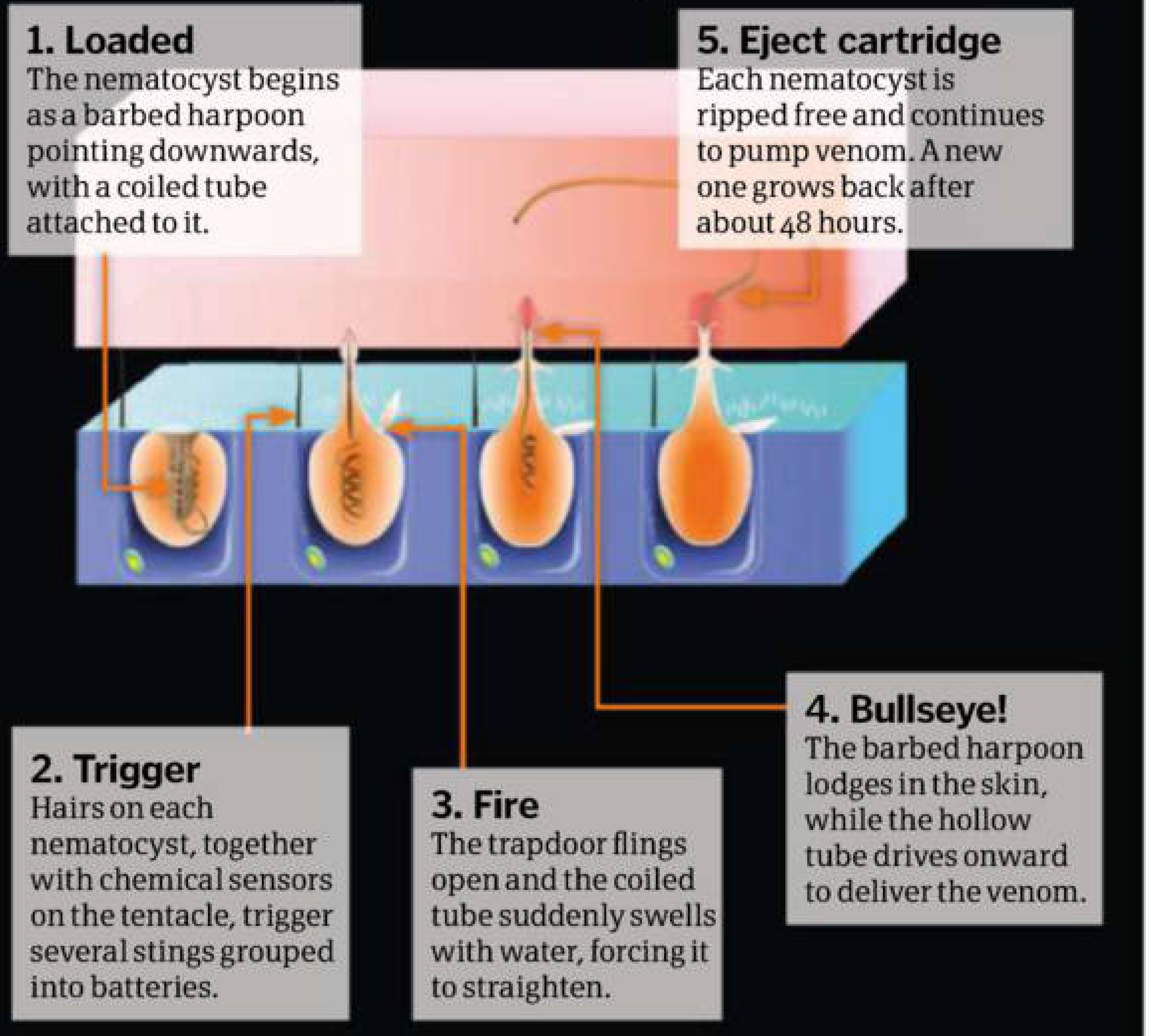
Number of stings per tentacle
500,000

Time to kill
2-5 minutes

Average number of humans killed each year
40

Microscopic harpoons

Jellyfish tentacles are lined with batteries of stinging cells called nematocysts – see how they work here



1. Loaded
The nematocyst begins as a barbed harpoon pointing downwards, with a coiled tube attached to it.

2. Trigger
Hairs on each nematocyst, together with chemical sensors on the tentacle, trigger several stings grouped into batteries.

3. Fire
The trapdoor flings open and the coiled tube suddenly swells with water, forcing it to straighten.

4. Bullseye!
The barbed harpoon lodges in the skin, while the hollow tube drives onward to deliver the venom.

5. Eject cartridge
Each nematocyst is ripped free and continues to pump venom. A new one grows back after about 48 hours.

ATTACK STATS

Top speed on land
40km/h (25mph)

Bite strength
350N

Attack triggers
Territory encroachment, loud noises, prey behaviours

Average number of humans killed each year
100

Dogs kill at least 20 times more people than wolves do

DOG

Friend or foe?

- **Weight** 50kg (110lb) • **Habitat** Our homes • **Location** Worldwide
- **Diet** Commercial dog food • **Kill tactic** Bite to the throat

Dogs have lived alongside humans for 30,000 years. In that time our ancestors have used selective breeding to make them more docile and friendly than their wolf ancestors – or have they? Around 4.7 million people are bitten by dogs and 26 people killed each year in the US alone. Most of these attacks are from the 'Molosser' category of breeds, which includes the boxer, great dane and rottweiler. These are heavy dogs, once bred for guarding, hunting and attacking. The victims are mostly infants who have wandered into a neighbour's garden, babies in their prams and the elderly. Running or snatching your hand away can trigger a predator response that can quickly escalate. But what makes dogs so deadly is that we generally take them for granted; always treat a hound with respect.

ATTACK STATS

Top speed on land
48km/h (30mph)

Claw size
12.5cm (4.9in)

Jump height
1.5m (4.9ft)

Confirmed human fatalities
1

SOUTHERN CASSOWARY

The Queensland slasher

- **Height** 1.7m (4.9ft) • **Habitat** Tropical rainforest • **Location** Indonesia, Australasia
- **Diet** Fruit, insects, fungi • **Kill tactic** Kick/slash

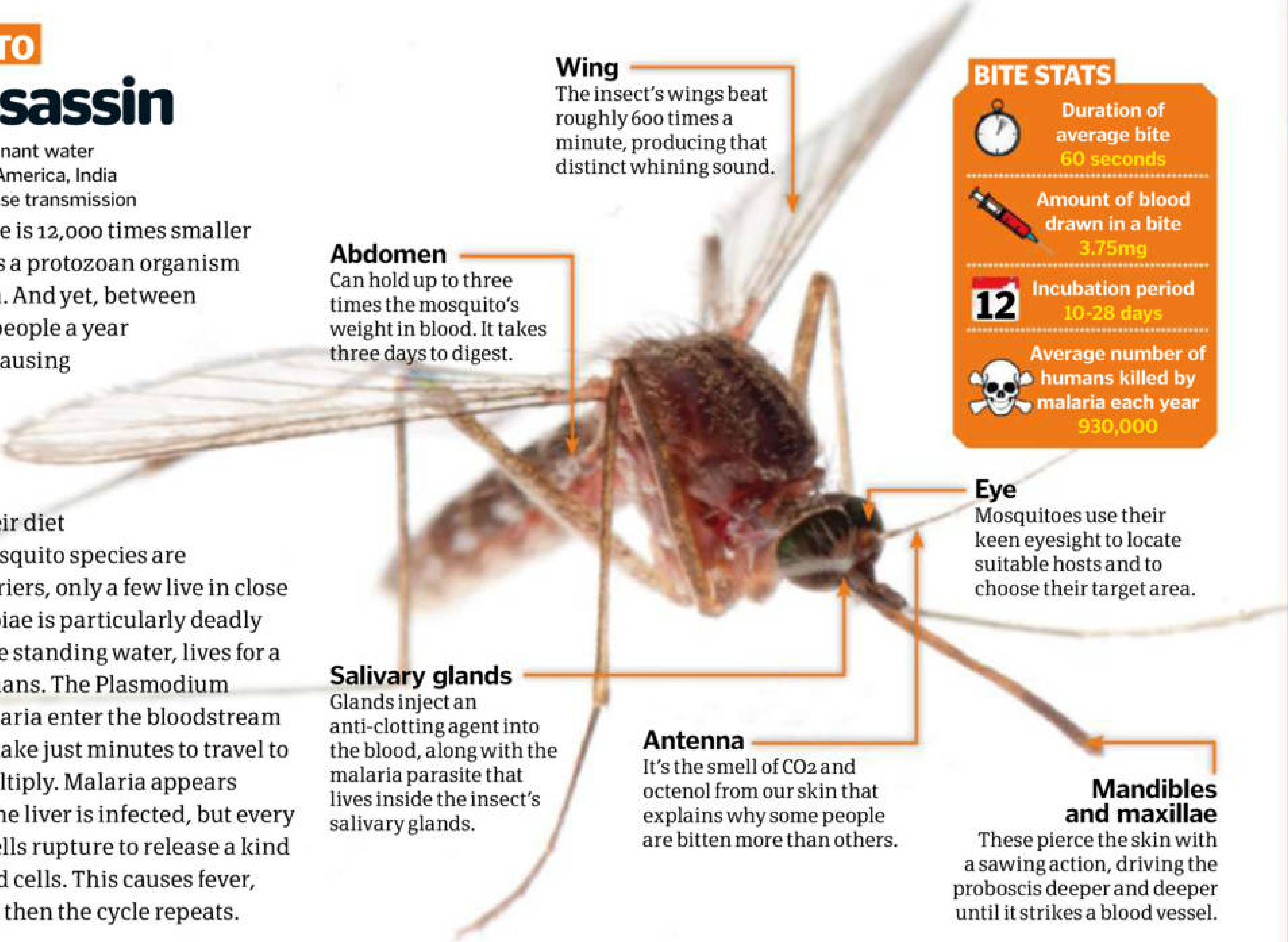
The southern cassowary is the second heaviest bird on Earth, after the ostrich, and is also the only other bird known to have attacked and killed humans. Records of fatalities only exist for Queensland, Australia, and don't include attacks on natives in Indonesia and New Guinea. The southern cassowary is most distinctive for its bright blue neck and a bony crest on its head. The crest is sometimes used to butt victims as the bird charges, but most injuries are caused by its kick. The claw of each inner toe is like a paring knife and the cassowary can jump to chest height before slashing. Humans have had their throats cut by a single strike and the force of the kick alone is enough to cause internal bleeding.

ANOPHELES MOSQUITO

The silent assassin

- **Length** 15mm (0.6in) • **Habitat** Stagnant water
- **Location** Sub-Saharan Africa, South America, India
- **Diet** Nectar, blood • **Kill tactic** Disease transmission

The mosquito Anopheles gambiae is 12,000 times smaller than a human. Inside its mouth is a protozoan organism that is 12,000 times smaller again. And yet, between them, they kill almost a million people a year worldwide by transmitting and causing malaria. Male mosquitoes eat plant nectar and are quite harmless. The female eats nectar too, but some species also bite mammals to supplement their diet with protein. Although many mosquito species are capable of becoming disease carriers, only a few live in close contact with us. Anopheles gambiae is particularly deadly because it breeds in any available standing water, lives for a long time and prefers to bite humans. The Plasmodium parasites that actually cause malaria enter the bloodstream along with the insect saliva and take just minutes to travel to the liver, where they begin to multiply. Malaria appears largely dormant as long as only the liver is infected, but every few weeks or months, the liver cells rupture to release a kind of spore cell that infects red blood cells. This causes fever, vomiting, seizures and anaemia, then the cycle repeats.



Wing
The insect's wings beat roughly 600 times a minute, producing that distinct whining sound.

Abdomen
Can hold up to three times the mosquito's weight in blood. It takes three days to digest.

Eye
Mosquitoes use their keen eyesight to locate suitable hosts and to choose their target area.

Salivary glands
Glands inject an anti-clotting agent into the blood, along with the malaria parasite that lives inside the insect's salivary glands.

Antenna
It's the smell of CO2 and octenol from our skin that explains why some people are bitten more than others.

Mandibles and maxillae
These pierce the skin with a sawing action, driving the proboscis deeper and deeper until it strikes a blood vessel.

BITE STATS

Duration of average bite	60 seconds
Amount of blood drawn in a bite	3.75mg
Incubation period	10-28 days
Average number of humans killed by malaria each year	930,000

POLAR BEAR

Ice-cold killer

- **Weight** 550kg (1,213lb) • **Habitat** Sea ice
- **Location** Arctic Circle • **Diet** Ringed seals, bearded seals • **Kill tactic** Skull-crushing bite

An adult male polar bear can rear up over 2.1 metres (seven feet) on its hind legs and weighs twice as much as a silverback gorilla. He can outrun you and outswim you and a swipe from his paw or a bite from his jaws will be the last thing you see. In the wild, polar bears wait next to holes in the sea ice and, when they smell the breath of a seal, they haul it out of the water with one paw and crush its skull with a single bite. Polar bears have been observed taking on one-ton walruses that have metre-long tusks and even beluga whales. Adult polar bears get most of their energy from the fat in blubber and seldom eat land animals. The rare attacks on humans mostly occur in autumn when sea ice is all but gone so they can't catch seals.

Polar bears can swim up to 322km (200mi) from land

ATTACK STATS

Top speed on land	40km/h (25mph)
Bite strength	1,650N
Food consumption	46 seals/year
Average number of humans killed each year	<1

BLACK MAMBA

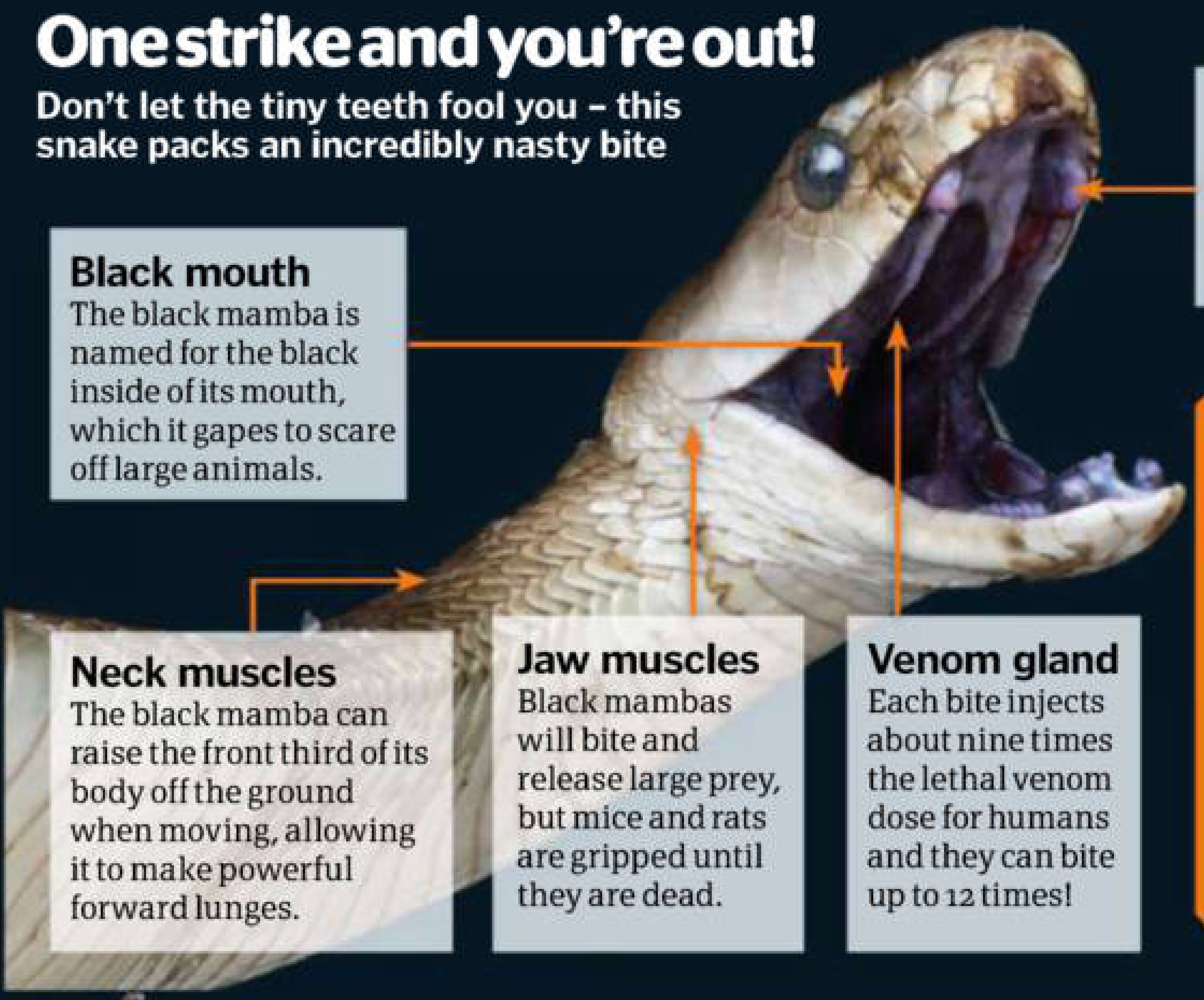
Fatal fangs

• **Length** 3m (9.8ft) • **Habitat** Savannah, woodland and farmland • **Location** Central and eastern Africa • **Diet** Rats, bush babies, chickens, other snakes • **Kill tactic** Venom

The black mamba is Africa's longest venomous snake. It generally keeps away from humans and is responsible for far fewer snakebite cases than the cobra, viper or krait, but it is very aggressive and has the fastest-acting venom of any serpent. Without antivenom, a bite is invariably lethal to humans. Since the venom spreads so quickly in the body, victims can die within 20 minutes. The black mamba can rear up high and often attacks the body or even the head, striking several times. The venom causes dizziness, paralysis, acute abdominal pain and heart failure. Even if the victim is treated with antivenom, paralysis can be permanent.

One strike and you're out!

Don't let the tiny teeth fool you – this snake packs an incredibly nasty bite



Short fang A black mamba has short fangs which do not fold flat inside the mouth.

Black mouth The black mamba is named for the black inside of its mouth, which it gapes to scare off large animals.

Neck muscles The black mamba can raise the front third of its body off the ground when moving, allowing it to make powerful forward lunges.

Jaw muscles Black mambas will bite and release large prey, but mice and rats are gripped until they are dead.

Venom gland Each bite injects about nine times the lethal venom dose for humans and they can bite up to 12 times!

BITE STATS

Amount of venom injected	100mg
Fang length	5mm (0.02in)
Time to kill	20 minutes
Average number of humans killed each year	1,000 (estimated)

You're most likely to be bitten by a male Sydney funnel-web

SYDNEY FUNNEL-WEB

The venomous villain

• **Size** 4cm (1.6in) • **Habitat** Under rocks and logs • **Location** Within 100km (62mi) of Sydney, Australia • **Diet** Insects, frogs, lizards • **Kill tactic** Venom

The female Sydney funnel-web spider spends most of her time in a burrow, monitoring the trip wires from her funnel-shaped web. The male, on the other hand, wanders out in warm weather, looking for females. This means you are most likely to be bitten by a male, which is a problem because its venom is six times more powerful than the female's. Sydney funnel-webs are super-aggressive and won't flee if challenged. Instead they will bite multiple times to inject as much venom as possible. The venom contains atracotoxin, which causes muscle twitching, low blood pressure and respiratory failure. Most mammals have a high immunity to Sydney funnel-web venom, but humans are acutely sensitive. The relatively low number of deaths is due to the spider's limited distribution and because a very effective antivenom exists.

BITE STATS

Fang length	Amount of venom injected	Time to kill	Confirmed human fatalities
6mm (0.2in)	1.7mg	28 minutes	14

KOMODO DRAGON

An ambush predator

• **Length** 3m (9.8ft) • **Habitat** Open grassland and forest • **Location** Indonesia • **Diet** Deer, carrion • **Kill tactic** Bite

There are very few confirmed attacks on humans by Komodo dragons, and even fewer fatalities, but this is mainly because they are very rare. There are fewer than 5,000 in the wild, spread across five remote islands in Indonesia. Komodo dragons are determined predators that normally attack from ambush, but can run at 19 kilometres (12 miles) per hour and even climb trees to reach prey. Their jaws have a bite force that is actually less than a domestic cat's, so they don't kill by crushing. Instead they will hold down prey with their heavy forelimbs and slice chunks out of their victim with incredibly sharp teeth. Komodo teeth also have a layer of living tissue covering them that gets torn as they feed. The mixture of blood, saliva and carrion in their mouths creates a breeding ground for a range of toxic bacteria and, even if prey makes a getaway, bite wounds are very likely to become septic. Komodo dragons also have venom glands that can inhibit blood clotting and induce muscle paralysis.

ATTACK STATS

Smell range	9.5km (5.9mi)
Bite strength	70N
Food consumption	12 meals per year
Confirmed human fatalities	2 in 40 years

Komodos force large prey down their throat by ramming against a tree!

HIPPOPOTAMUS

The big mouth

• **Length** 4.5m (14.8ft) • **Habitat** Savannah and forest riverbanks • **Location** Sub-Saharan Africa • **Diet** Grass • **Kill tactic** Bite

The hippopotamus has long had the reputation of Africa's most dangerous animal. Although it only eats grass, the hippo is extremely short-tempered. Their massive canine tusks are razor sharp, half a metre (1.6 feet) long and used purely as weapons. Hippos can open their mouths wider than any other land animal; there are even tales of luckless hunters having their head and shoulders bitten clean off! These animals are very territorial in the water, with males defending their harem and females protecting their calves. Boats are overturned without provocation and the tipped-out occupants often killed. On land hippos aren't so territorial, but will still attack safari tours in their vehicles, as well as lions and crocodiles. Fatal attacks have declined in recent years, but only because the hippo itself is growing rarer.

The hippo has the widest mouth on land and equally huge canines ideal for fighting

ATTACK STATS

Size of mouth gape	150° (humans can only open 45°)
Bite strength	8,100N
Length of tusk/tooth	50cm (19.7in)
Average number of humans killed each year	150 (estimated)

OCEANIC WHITETIP SHARK

Deep-sea destroyer

• **Length** 3m (9.8ft) • **Habitat** Deep waters warmer than 18°C (64°F) • **Location** Tropical seas • **Diet** Squid, fish • **Kill tactic** Bite, feeding frenzy transmission

According to the International Shark Attack File, there are only seven recorded unprovoked attacks on humans by oceanic whitetip sharks. The great white shark has 139 unprovoked attacks to its name since 1990, with 29 of them fatal. But what elevates the oceanic whitetip shark to the ranks of the truly deadly is the number of attacks that go unrecorded. This is a deep-water species that rarely comes into contact with swimmers or surfers, but it is believed to be responsible for a large number of deaths among shipwreck victims. In particular, during World War II, the USS Indianapolis and the troop ship Nova Scotia were both torpedoed by submarines in tropical waters. Hundreds of the initial survivors are thought to have been eaten by oceanic whitetip sharks in both cases.

Whitetips may have once been the most abundant large predators

BITE STATS

Swim speed	Slow
Bite size	20cm (7.9in) diameter
Number of teeth	54-60
Average number of humans killed each year	Unrecorded

© Thinkstock; Alamy; Corbis; Getty; SPL

Deadly dinosaurs

Until they were wiped out 65 million years ago, dinosaurs ruled the Earth. Among them, monstrous beasts stamped their authority over the menagerie, devouring all who stood in their way. These were the dinosaur kings, the largest carnivores the world has ever seen

"Among them, huge behemoths with skeletons over 16 metres long and six metres tall, with skulls the size of bath tubs have surfaced"

Evolving from archosaurs (large lizards) in the latter part of the middle Triassic period, dinosaurs quickly gained a strong and prolific foothold all over Pangaea, the super continent which all our continents were once part of. Indeed, as the dominant terrestrial vertebrates through the Jurassic and Cretaceous periods, thousands of species of dinosaur have been unearthed as fossils by palaeontologists all over the world, with new discoveries being presented every year. Among them, huge behemoths with skeletons over 16 metres long and six metres tall, with skulls the size of bath tubs have surfaced and delivered a scary and disturbing glimpse into the creatures that once prowled the countries we still live in today.

Among the largest of these giants, a group of massive carnivorous theropods (bipedal dinosaurs) emerged throughout the Jurassic and Cretaceous periods, casting a shadow over the rest of the dinosaur population. The most famous of these is the Tyrannosaurus Rex, as made popular by the *Jurassic Park* films, however this type of theropod was but one of a host of killers and, amazingly, not the largest! Historically, of course, the reign of these carnivorous kings was cut short in the mass-extinction of the dinosaur population at the close of the Cretaceous period, when a 110-mile radius asteroid crashed into the Yucatán Peninsula, setting off a chain reaction (tsunamis, dust clouds, temperature variation, food chain collapse) of events that eventually led to their extermination.

Here, though, we explore the giddy heights of the pinnacle of dinosaur evolution, the time when nothing living on Earth could match these beasts for size and strength. Better run for cover then, as things are about to get prehistoric…

Image used with kind permission of Jerry Lofaro

The statistics...

Spinosaurus

Height: 6 metres

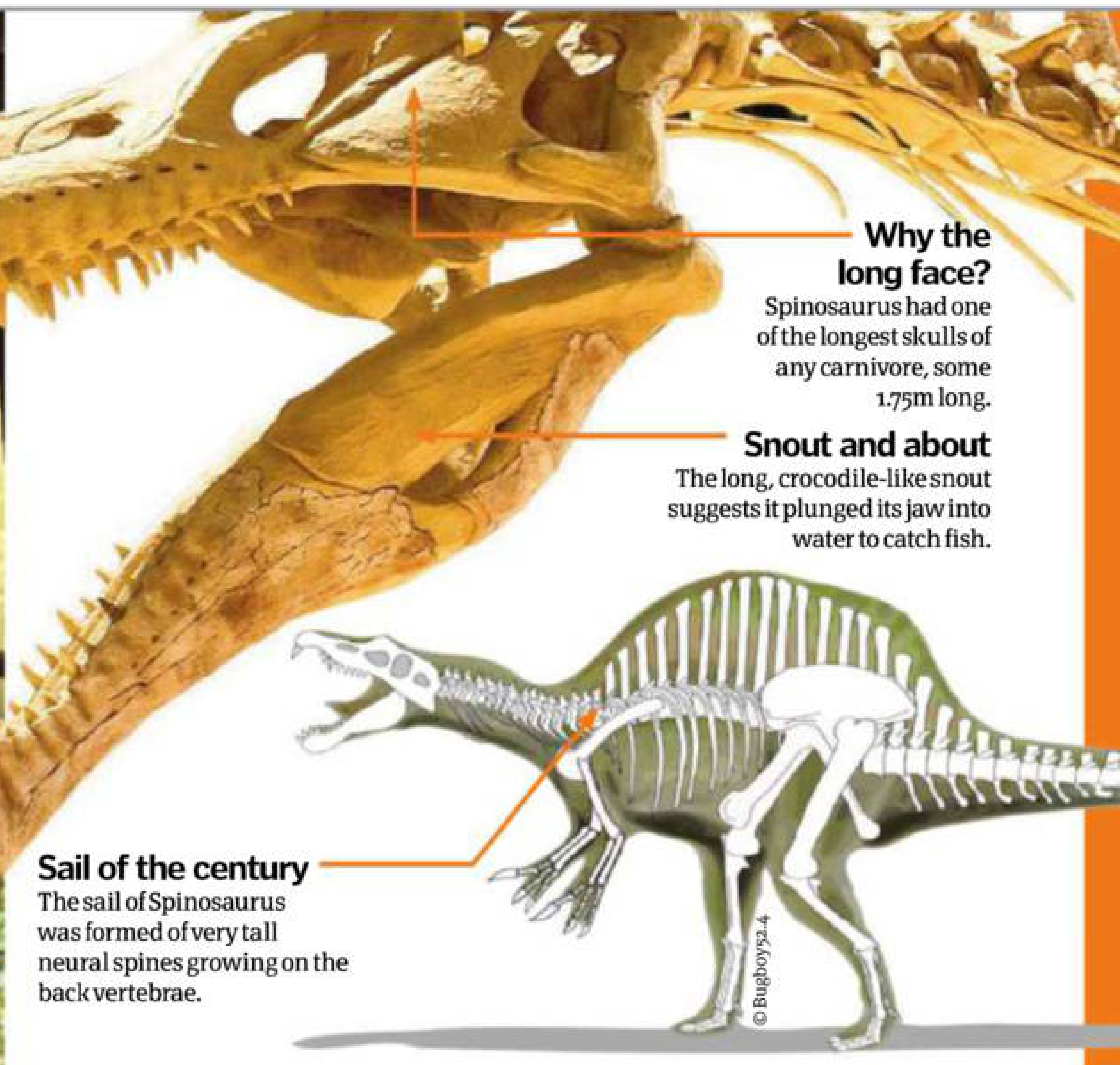
Length: 16 metres

Weight: 12 tons

Head size: 1.75 metres

Interesting fact: The spines on the Spinosaurus grew up to two metres tall

Fear factor: 9/10


Why the long face?
Spinosaurus had one of the longest skulls of any carnivore, some 1.75m long.

Snout and about
The long, crocodile-like snout suggests it plunged its jaw into water to catch fish.

Sail of the century
The sail of Spinosaurus was formed of very tall neural spines growing on the back vertebrae.

© Bugboy52.4

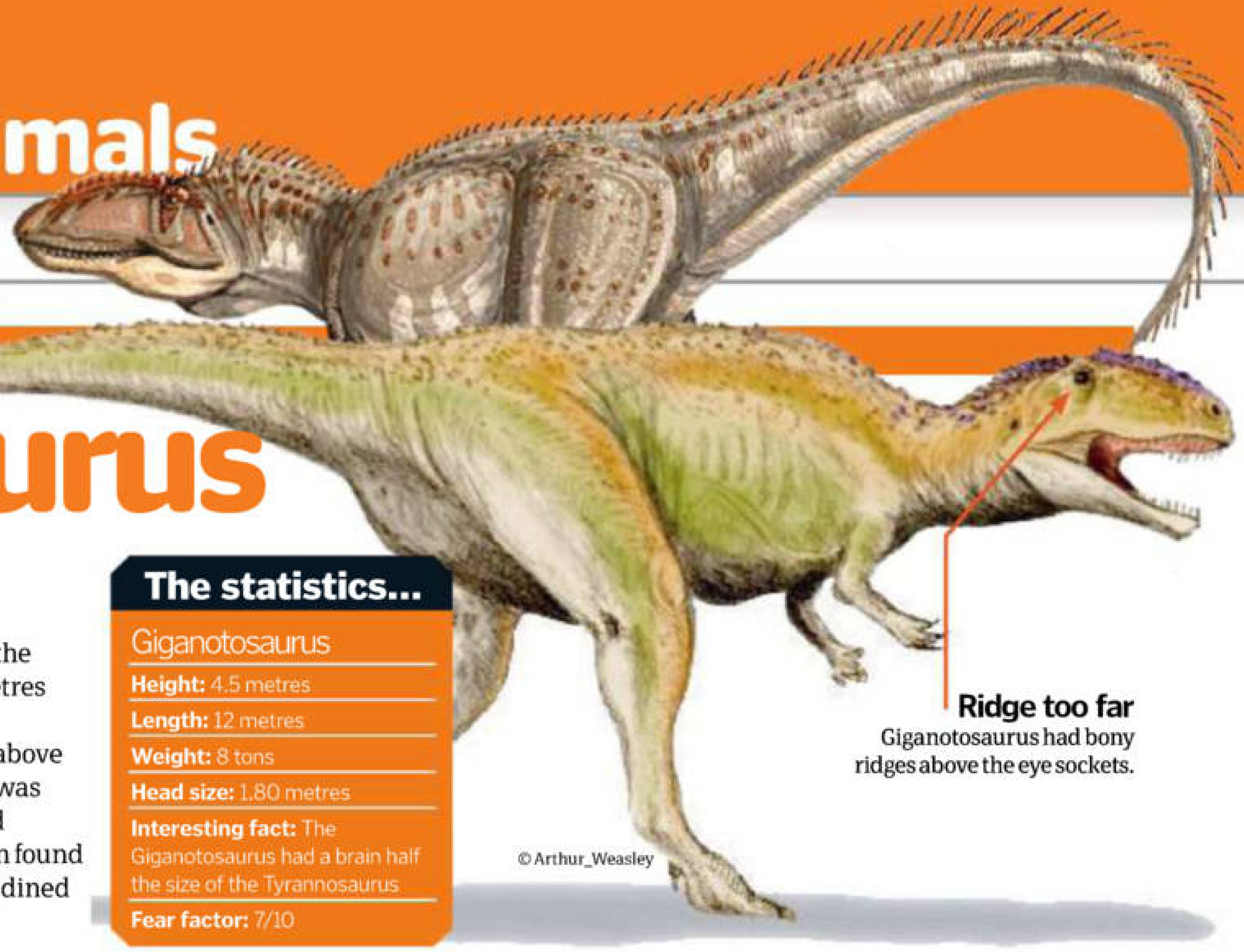
CARNIVORE 1

Spinosaurus

Step aside T-Rex, this was the ultimate theropod...

Bigger and arguably meaner than the Tyrannosaurus Rex, the Spinosaurus is thought to be the largest theropod dinosaur to ever roam the planet. Over 16 metres long, six metres high and weighing a monumental 12 tons, the Spinosaurus was a relatively common animal in the late Cretaceous period. Palaeontologists have found fossilised remains of the Spinosaurus in Morocco, Libya and Egypt, including a well preserved but now destroyed (blown-up in a World War II bombing run) specimen that included the lower jaw and vertebrae with complete spines. Spinosaurus was typical for a large theropod but differed in its skull and vertebrae construction. The snout of the 1.75-metre skull was long like a crocodile, with the nostril openings placed well back from the tip. Its teeth were also conical, rounded in a cross section and did not contain any serrations – these features suggest that the Spinosaurus plunged its jaw into water in order to catch fish. However, considering its size, jaw strength and number of teeth, it equally had no trouble in hunting small, medium and other large dinosaurs on land.

Not a dinosaur you'd want to meet down a dark alley...



CARNIVORE 2

Giganotosaurus

The dinosaur with a big name to live up to, but was it as colossal as it sounds?

Meaning 'giant southern lizard', the Giganotosaurus was roughly the same size as the largest Tyrannosaurus Rex, measuring over 12 metres long, five metres tall and weighing over eight tons. The skull of the Giganotosaurus was adorned with shelf-like bony ridges, notably above the eye sockets and had low horn-like projections, while the neck was considerably thicker than that of the Spinosaurus, with a stout and powerful head supported by it. Giganotosaurus remains have been found in Argentina and it has been postulated by palaeontologists that it dined mainly on medium-sized dinosaurs such as Andesaurus.

The statistics...

Giganotosaurus

Height: 4.5 metres

Length: 12 metres

Weight: 8 tons

Head size: 1.80 metres

Interesting fact: The Giganotosaurus had a brain half the size of the Tyrannosaurus

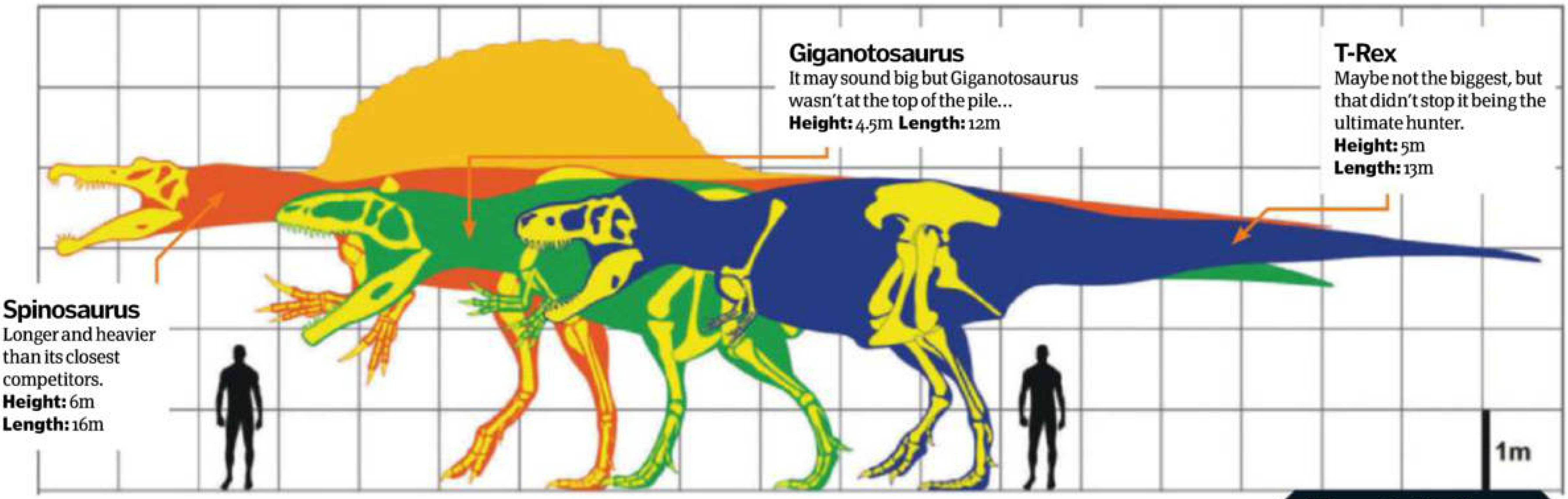
Fear factor: 7/10

Ridge too far
Giganotosaurus had bony ridges above the eye sockets.

© Arthur_Weasley

Size comparison

Who was the real king of the dinosaurs?



Giganotosaurus
It may sound big but Giganotosaurus wasn't at the top of the pile…
Height: 4.5m **Length:** 12m

T-Rex
Maybe not the biggest, but that didn't stop it being the ultimate hunter.
Height: 5m
Length: 13m

Spinosaurus
Longer and heavier than its closest competitors.
Height: 6m
Length: 16m

CARNIVORE 3

Carcharodontosaurus

Not the world's easiest name to pronounce…

Named in 1931, the African Carcharodontosaurus was a huge theropod with serrated teeth similar to the great white shark. The skull of the Carcharodontosaurus was very narrow although it reached up to 1.6 metres in length, while its body was taller at the back than at the front, giving it a low, streamlined physicality. The thigh muscles of the Carcharodontosaurus were some of the largest of any dinosaur and this, in partnership with its narrow streamlined frame and ferocious sharp teeth, made chasing down and devouring prey elementary. Arguably the quickest of the carnivorous theropods, the archarodontosaurus was a fearsome predator. Fossilised remains have been found in Morocco, Tunisia and Egypt.

The statistics...

Carcharodontosaurus

Height: 4 metres

Length: 11 metres

Weight: 6 tons

Head size: 1.60 metres

Interesting fact: The Carcharodontosaurus could run at over 20mph

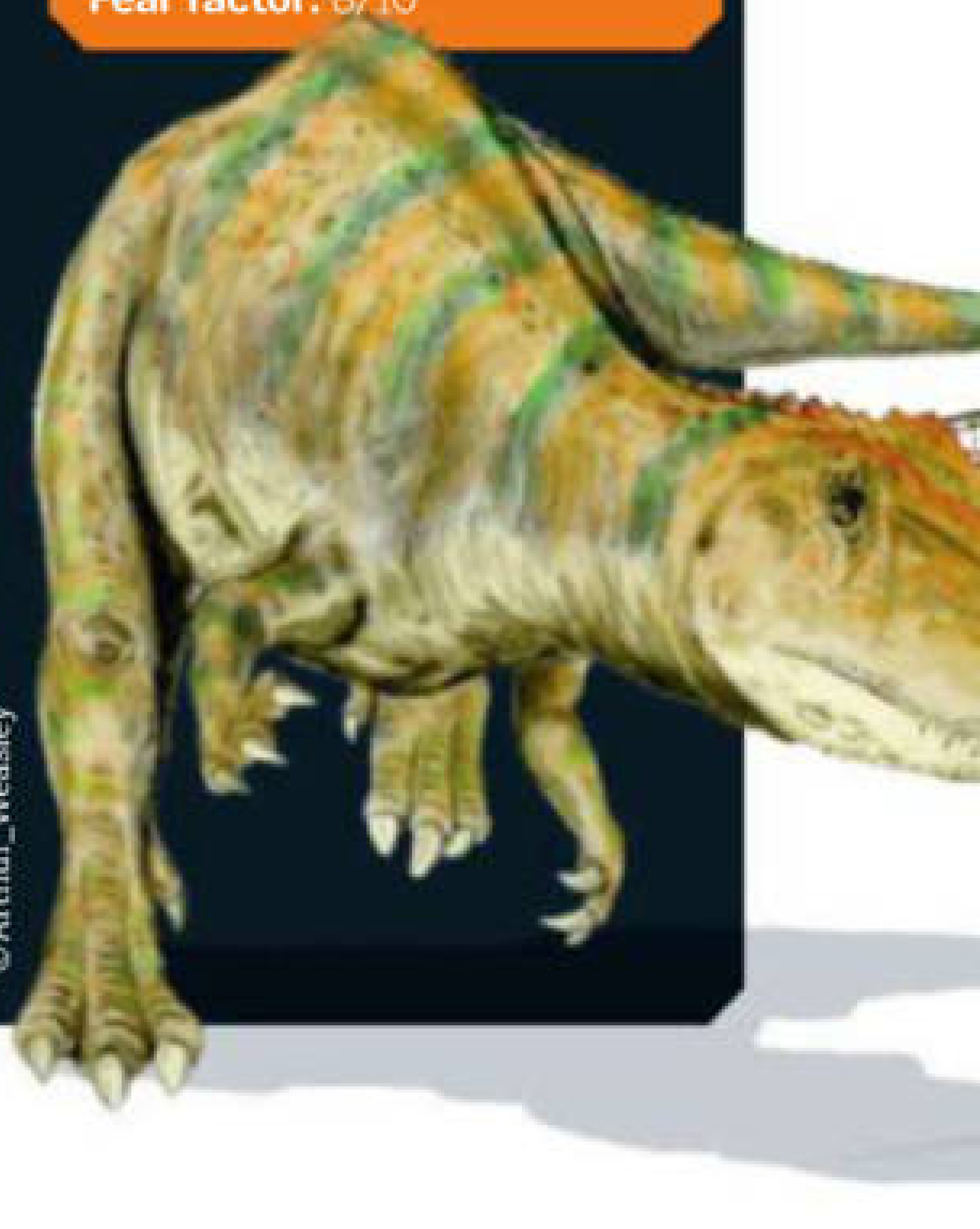
Fear factor: 8/10

© Didier Descouvens 2010

This incredible beast was named after its deadly serrated teeth

Shark-like teeth
The serrations in the teeth are very similar to a shark's.

© F.Fonseca



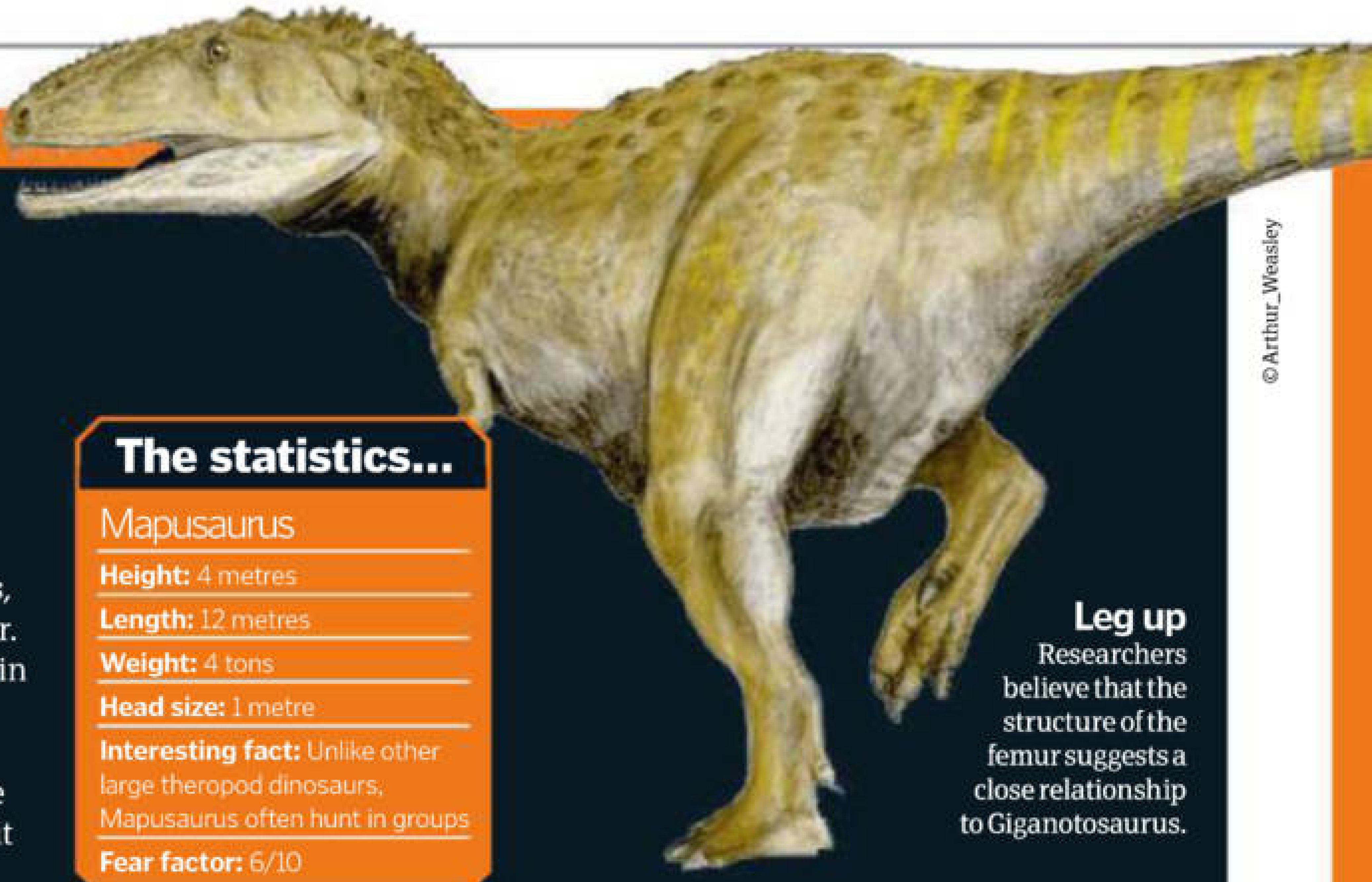
© Arthur_Weasley

CARNIVORE 4

Mapusaurus

The dinosaur that proved teamwork can be the best way to get a good meal

Dating from the late Cretaceous period and stalking the area that is now Argentina, the Mapusaurus was a close relative of the Giganotosaurus. Despite being one of the smaller giant carnivores, with a length of 12 metres, height of four metres and weight of four tons, it was still a fearsome predator. Interestingly, palaeontologists believe that the Mapusaurus would engage in group hunting activity, allowing groups of them to take down larger foes than they would be able to achieve on their own. The remains of the Mapusaurus were first excavated between 1997 and 2001 and now complete the majority of a full skeleton. Due to its connection to the Giganotosaurus, it shares many of the same characteristics.



Leg up
Researchers believe that the structure of the femur suggests a close relationship to Giganotosaurus.

© Arthur_Weasley

The statistics...

Mapusaurus

Height: 4 metres

Length: 12 metres

Weight: 4 tons

Head size: 1 metre

Interesting fact: Unlike other large theropod dinosaurs, Mapusaurus often hunt in groups

Fear factor: 6/10

CARNIVORE 5

Tyrannosaurus Rex

The most famous dinosaur of them all and the ultimate predator

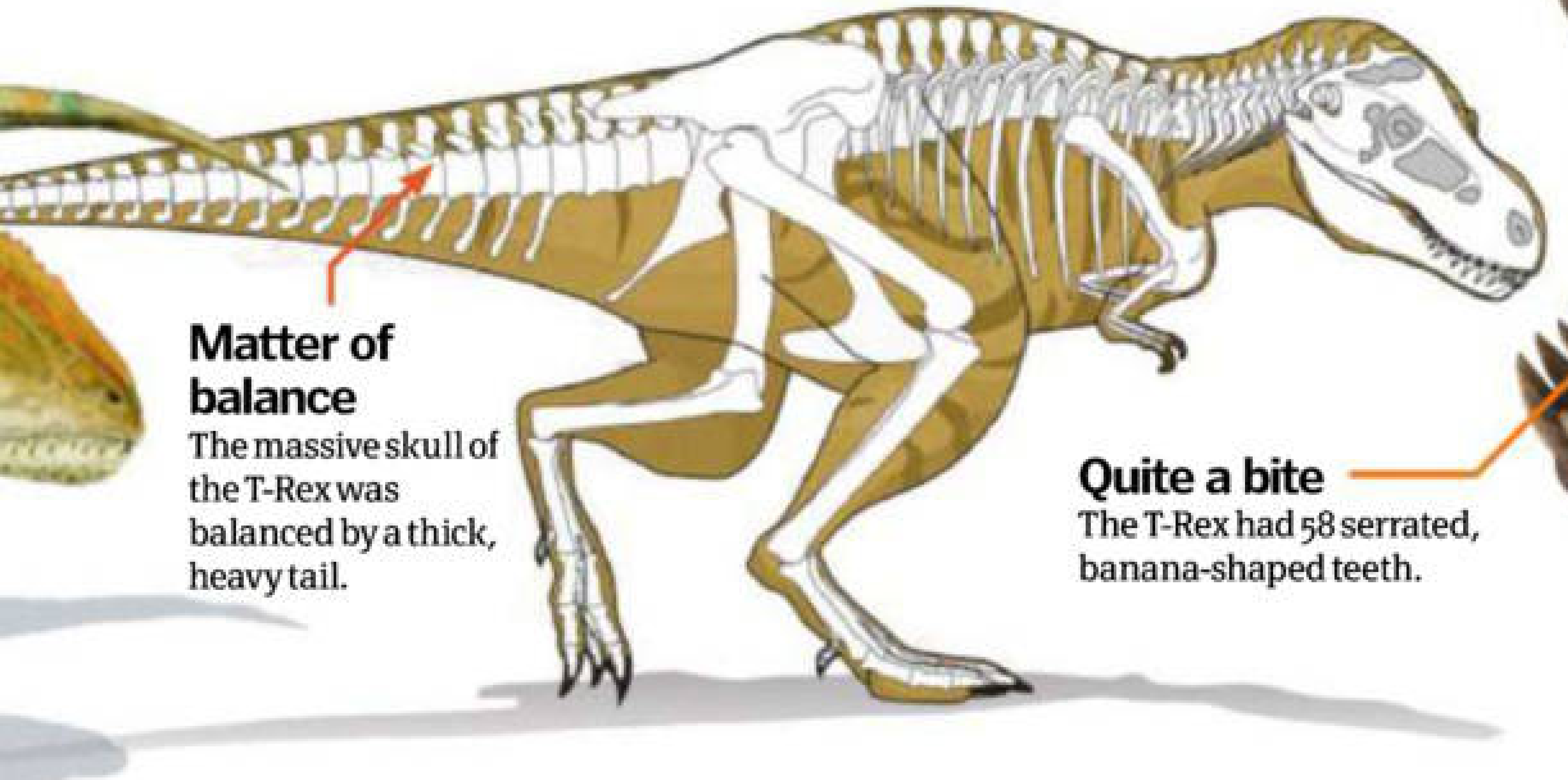
The T-Rex was one of the largest terrestrial carnivores in the world, with the estimated strength of its bite greater than that of any other animal that has ever existed on Earth. Standing at a height of five metres, measuring over 13 metres in length and weighing over nine tons, the T-Rex is considered to be one of the most fearsome hunters ever.

The body of the T-Rex was perfectly balanced, with a horizontal backbone positioned above the hips giving completely equal weight distribution. The head was also colossal, measuring 1.6 metres long and far bulkier than any other theropod, containing 58 serrated teeth and large forward-facing eye sockets giving it acute binocular vision. From fossilised remains of Tyrannosaurus faeces, palaeontologists have discovered that the T-Rex crushed bones of the prey it consumed. The T-Rex was prolific over the entire western North America.

A nice bit of colour… in case you didn't spot it running at you!

Good eyes
The T-Rex had binocular, colour vision

Quite a bite
The T-Rex had 58 serrated, banana-shaped teeth.



Matter of balance
The massive skull of the T-Rex was balanced by a thick, heavy tail.

The statistics...

Tyrannosaurus Rex

Height: 5 metres

Length: 13 metres

Weight: 9 tons

Head size: 1.6 metres

Interesting fact: The Tyrannosaurus Rex could consume 230kg of meat in a single bite

Fear factor: 10/10

"A frog's skin is permeable, allowing the frog to absorb both water and oxygen with it"

The life of frogs

Kissing one won't produce a prince, but there's plenty to love about frogs just the way they are

All frogs and toads are amphibians and members of the order Anura, which means 'without a tail' in ancient Greek. Although they are most plentiful in the tropics, frogs are found in all continents except Antarctica.

A frog's skin is permeable, allowing the frog to absorb both water and oxygen. This means these creatures can breathe even underwater for long periods. Species that must survive long periods of extreme cold use glucose produced by the liver as a type of antifreeze, which protects their organs from damage, even if the water in and around the frog completely turns into ice!

Frogs are largely carnivorous, and to survive they live mostly on insects. They hunt by sight, too, but they see better from farther away than they do close-up and they don't perceive still objects well either. However, they make up for this in their ability to detect moving prey, which many species can pluck out of the air with retractable sticky tongues. Their eye position means frogs can sit almost entirely submerged while still able to watch for potential food or predators.

When it comes to romance, the frog relies on sound rather than sight to find a mate. Males use enlarged mouths or throat pouches to amplify their call over long distances. Though not famous for their family life, some frogs show elaborate parental skills. Indeed, a few species in places without much accessible water raise their babies in specialised pouches in their skin or even in their mouths for the entire tadpole phase, before releasing them.

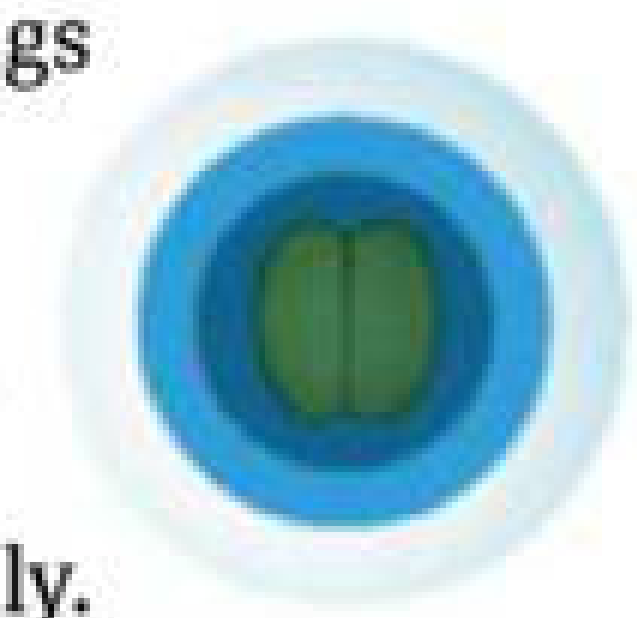
How frogs develop

See how a common frog undergoes an amazing transformation from egg to adult in around 16 weeks

Week 1

Frogspawn

When frog eggs are laid, the tiny embryo is enveloped in layers of protective jelly.



1-2

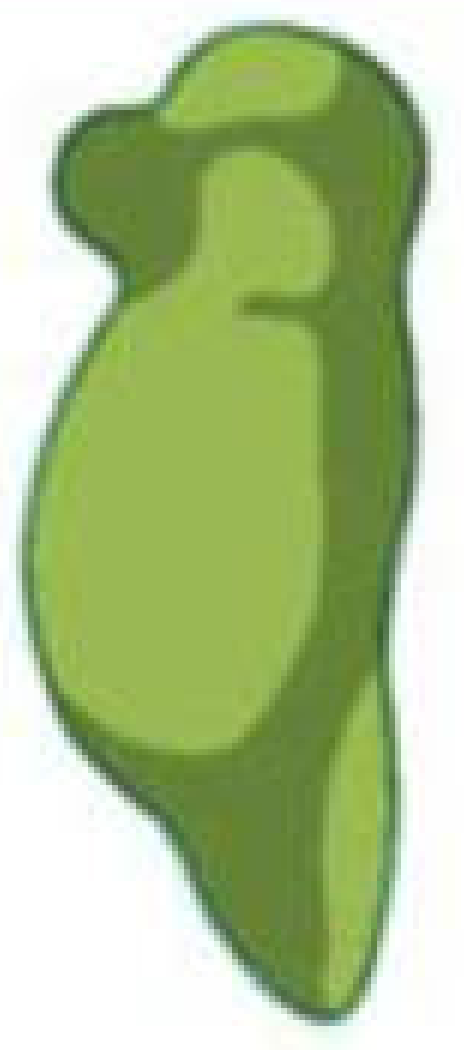
Larva

As the larva develops, it releases hormones which cause the egg to split apart.

2

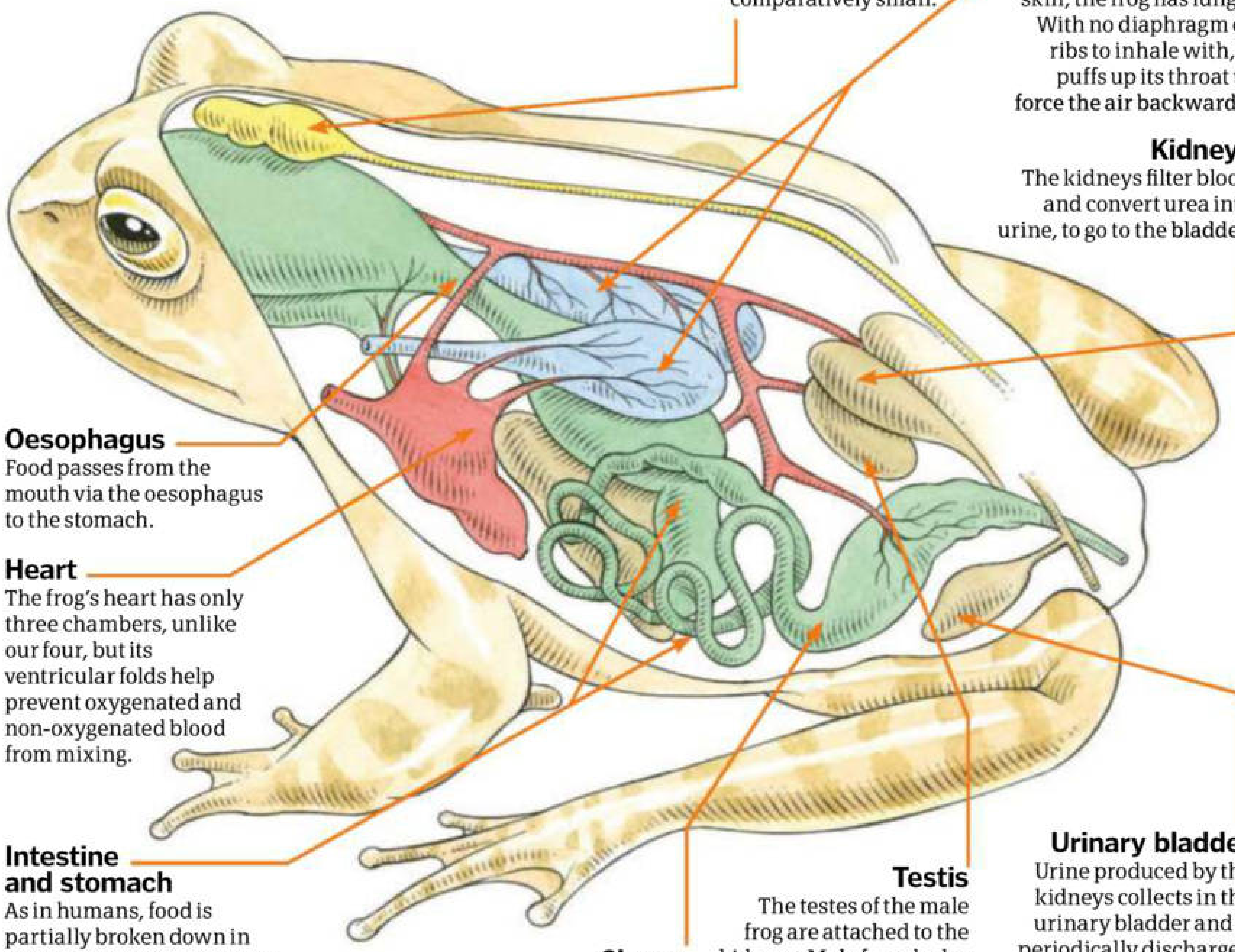
Hatchling

With few exceptions, tadpoles are fully aquatic, using their strong tails to propel them around in search of food.



What's inside a frog?

Often used to teach anatomy, frogs have a body plan much like our own – but with a few important differences…



Brain
The brain has the same main components ours do, but the cerebellum is comparatively small.

Lungs
Despite breathing via its skin, the frog has lungs. With no diaphragm or ribs to inhale with, it puffs up its throat to force the air backwards.

Kidneys
The kidneys filter blood and convert urea into urine, to go to the bladder.

Oesophagus
Food passes from the mouth via the oesophagus to the stomach.

Heart
The frog's heart has only three chambers, unlike our four, but its ventricular folds help prevent oxygenated and non-oxygenated blood from mixing.

Intestine and stomach
As in humans, food is partially broken down in the stomach before passing to the intestine, where most of the digestion takes place.

Cloaca
Liquid and solid waste, as well as sperm and eggs, all wind up in the cloaca, where they are ejected from the body via the cloacal vent.

Testis
The testes of the male frog are attached to the kidneys. Male frogs lack a penis, so sperm is ejected directly onto the eggs as they are being laid.

Urinary bladder
Urine produced by the kidneys collects in the urinary bladder and is periodically discharged into the cloaca.

The statistics…

Frog

Type: Amphibian

Order: Anura

Diet: Usually carnivorous, though often herbivorous at the tadpole stage of development

Average life span in the wild: Estimated at 4-15 years

Size: From 7.7mm (0.3in) up to 33cm (12.9in)

Distribution: Global, except Antarctica

Poison dart frogs

Bright, beautiful and potentially lethal, the Dendrobatidae family, aka poison dart frogs, let would-be predators know they should dine elsewhere. Their colourful skin exudes alkaloid compounds that put some of these tiny frogs among the most deadly vertebrates alive. However, they can't do it alone: poison dart frogs obtain their toxicity from their arthropod prey, eg mites. This means frogs born and raised in captivity are non-toxic, since they can't synthesise these compounds independently. The most toxic frogs produce batrachotoxins and less potent pumiliotoxins, both of which are cardiotoxins, causing muscle spasm, arrhythmia and death.

Spot the difference

Frog

Habitat: Frogs require a moist environment to live and many are fully aquatic.

Skin: Usually smooth and appears wet or slimy.

Body shape: Relatively long, slim bodies with pointy snouts as well as long hind legs.

Locomotion: Webbed feet, which they use to execute long jumps and to swim.

Head: Large protuberant eyes, and often a row of small cartilaginous teeth.

Eggs: Usually lay their eggs in a large gelatinous mass.

Defences: The main defence for most frogs is to hide or flee. Some species are highly toxic.

Toad

Habitat: Can withstand drier conditions so can spend more time on land.

Skin: Bumpy or warty-looking and also dryer.

Body shape: Chubby with a blunt snout and short limbs.

Locomotion: They walk or take short hops.

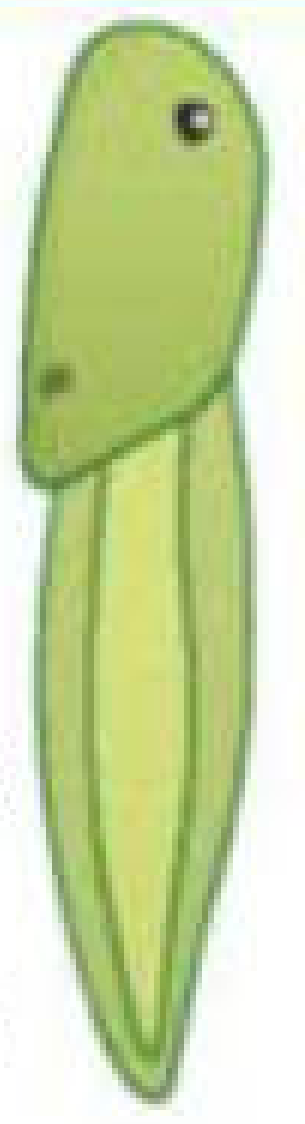
Head: Defined brow ridges but the eyes are not as bulgy. Toads have no teeth.

Eggs: Typically lay eggs in long strands but a few species of toad give birth to live young.

Defences: A large parotid gland behind each eye which can secrete poison, just like their skin can to a lesser extent.

3-10

Larval tadpole
Most frogs are carnivorous, but many tadpoles are herbivorous. They use spiral tooth ridges to scrape algae off rocks.

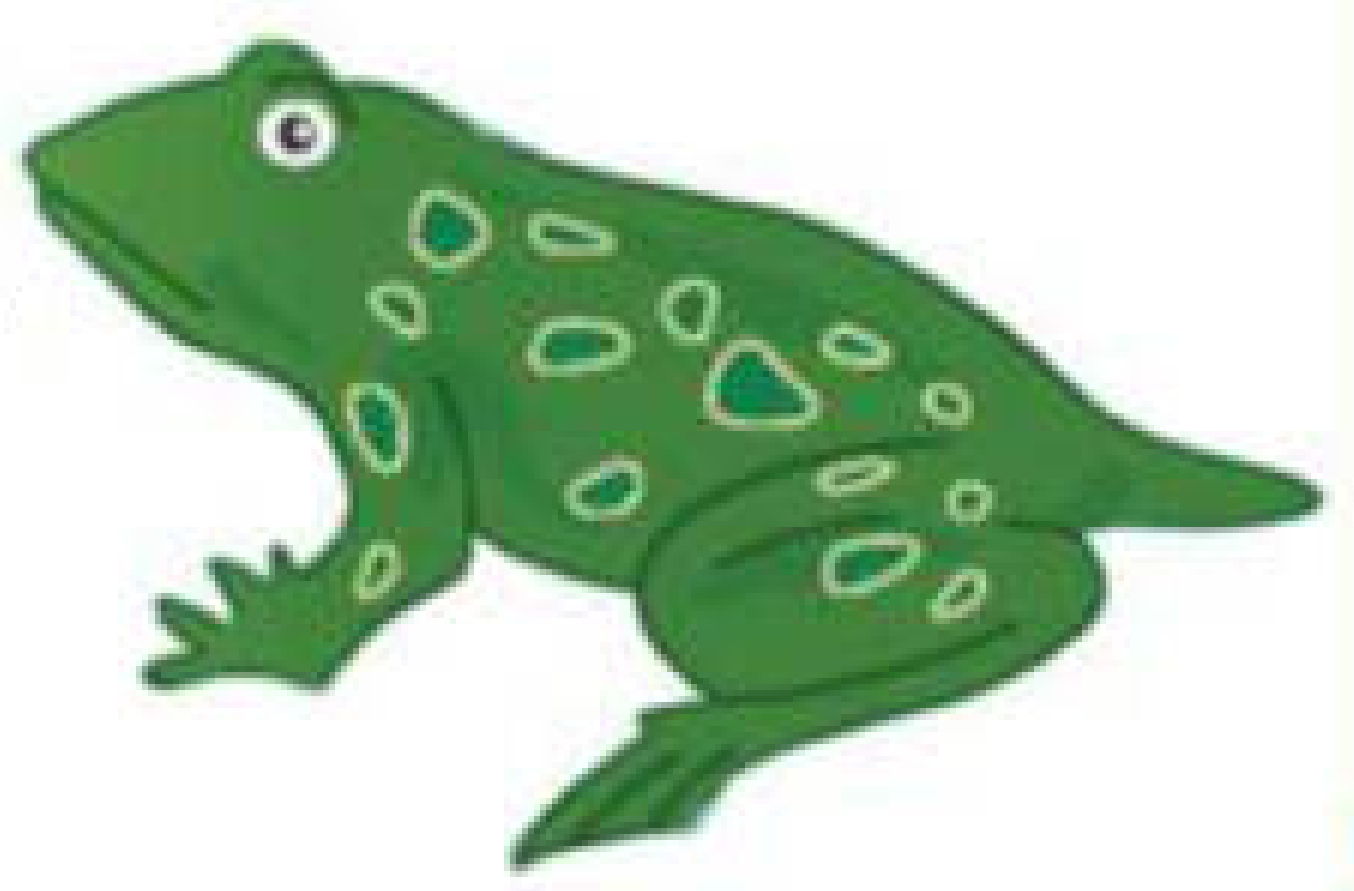


10-12

Froglet
Legs emerge from under the gill sac; the gut shortens; eyes shift and change; ear structures and skin glands develop.

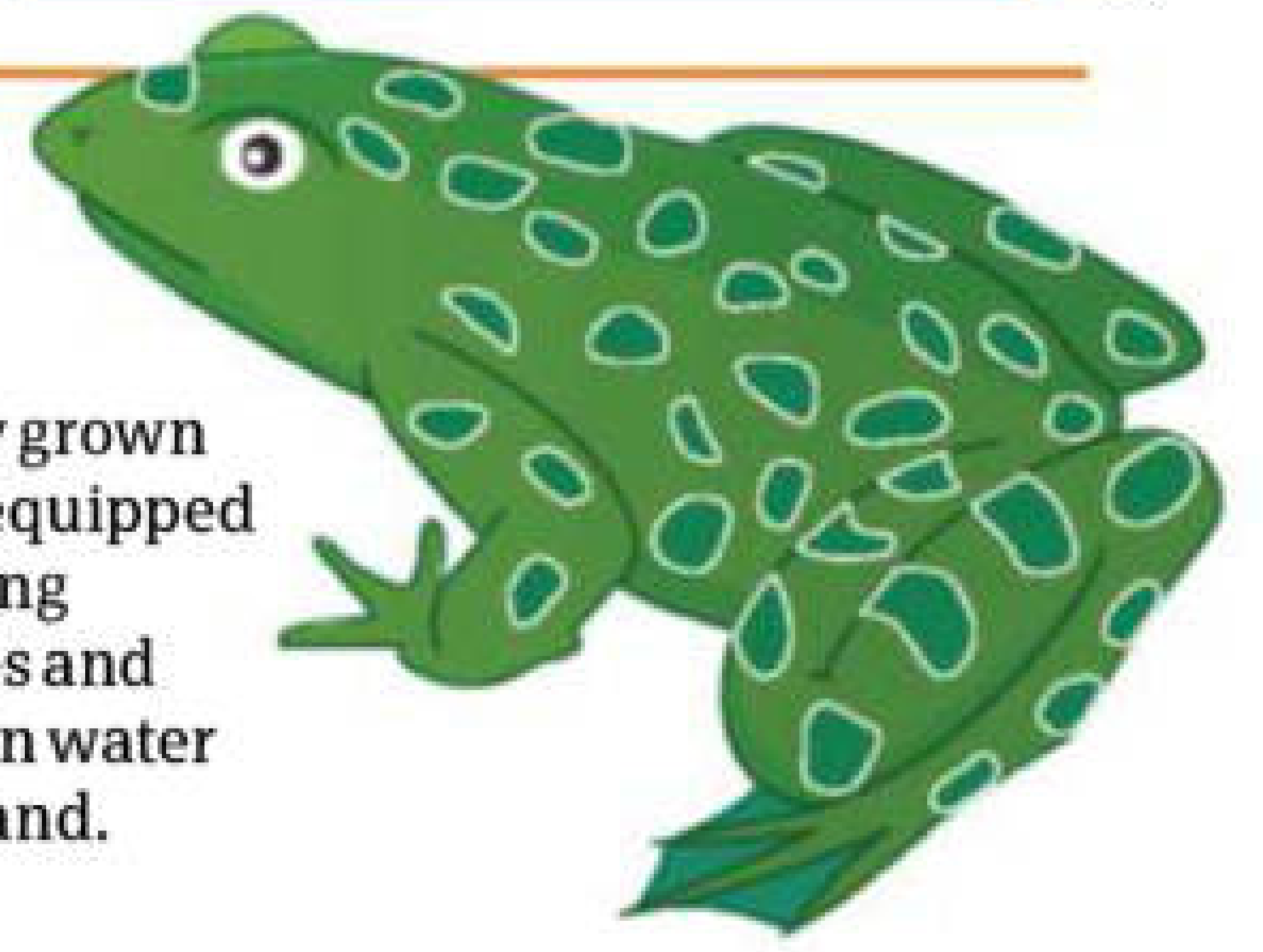
12-16

Teen frog
The tail is the last thing to disappear. The frog is nearly fully developed.



16

Adult
The fully grown adult is equipped to hop long distances and survive in water and on land.



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Elastic energy in the leg muscles transforms into mechanical energy during the leap

How do frogs leap?

Discover what enables this amphibian to jump up to 50 times its own body length

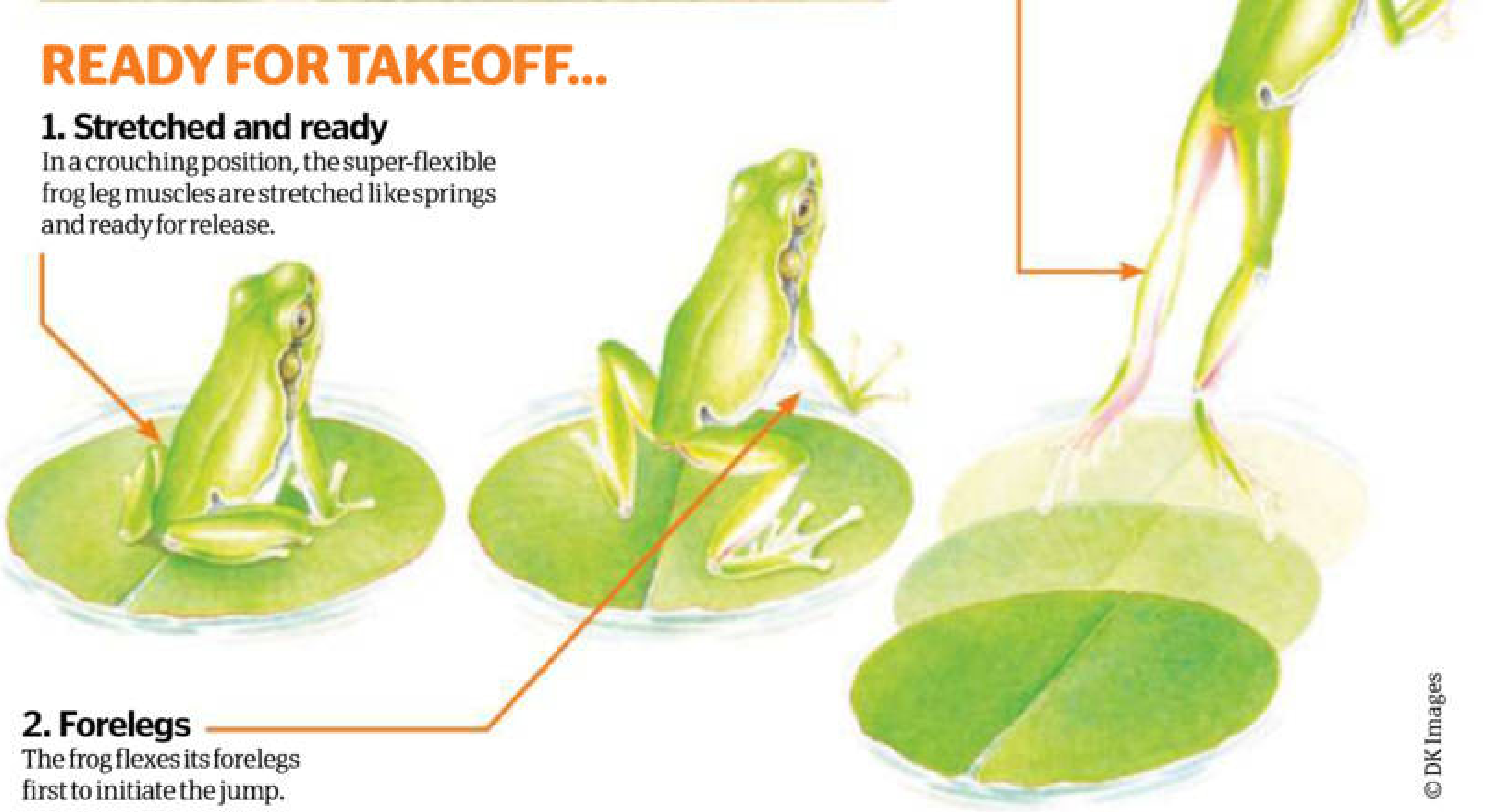
The secret to why frogs can jump so far is all in their legs. The ideal way for a frog to evade predators is to leap away in a split second. The amphibians have evolved extremely strong hind legs with specially fused leg bones and proportionally big feet, which are perfect for launching into the air over huge distances, because they enable the frog to push off against the ground for longer periods of time.

Using high-speed cameras to examine the anatomy of a frog as it jumps, researchers have discovered the mechanics of how a frog can travel so far. Pre-jump, the muscles in a frog's powerful hind legs are lengthened and stretched as they sit in the typical crouching position. Upon takeoff the muscles connecting the pelvis to the knee contract as the frog flies into the air, pulling the upper hind leg backwards and propelling the frog forwards. The muscles then stretch again once the frog has reached the ultimate height of its jump. These super-stretchy muscles store a huge amount of elastic energy, which in turn is transferred into mechanical energy.

The appropriately named rocket frog can jump a massive two metres (6.6 feet) – that's over 50 times its own body length. This is the equivalent of Olympic triple-jumper Jonathan Edwards jumping around 90 metres (295 feet) in one stride – let alone three.

One mighty leap can be the difference between life and death for a frog

READY FOR TAKEOFF…



1. Stretched and ready
In a crouching position, the super-flexible frog leg muscles are stretched like springs and ready for release.

2. Forelegs
The frog flexes its forelegs first to initiate the jump.

3. Hind legs
Simultaneously the hind legs extend to a vertical position and lock straight at the height of the kick. The thighs then swing round to the side and draw the legs back up into a bent position.

© DK Images

Super-snappy tongues

How do some amphibians and reptiles catch bugs with projectile tongues?

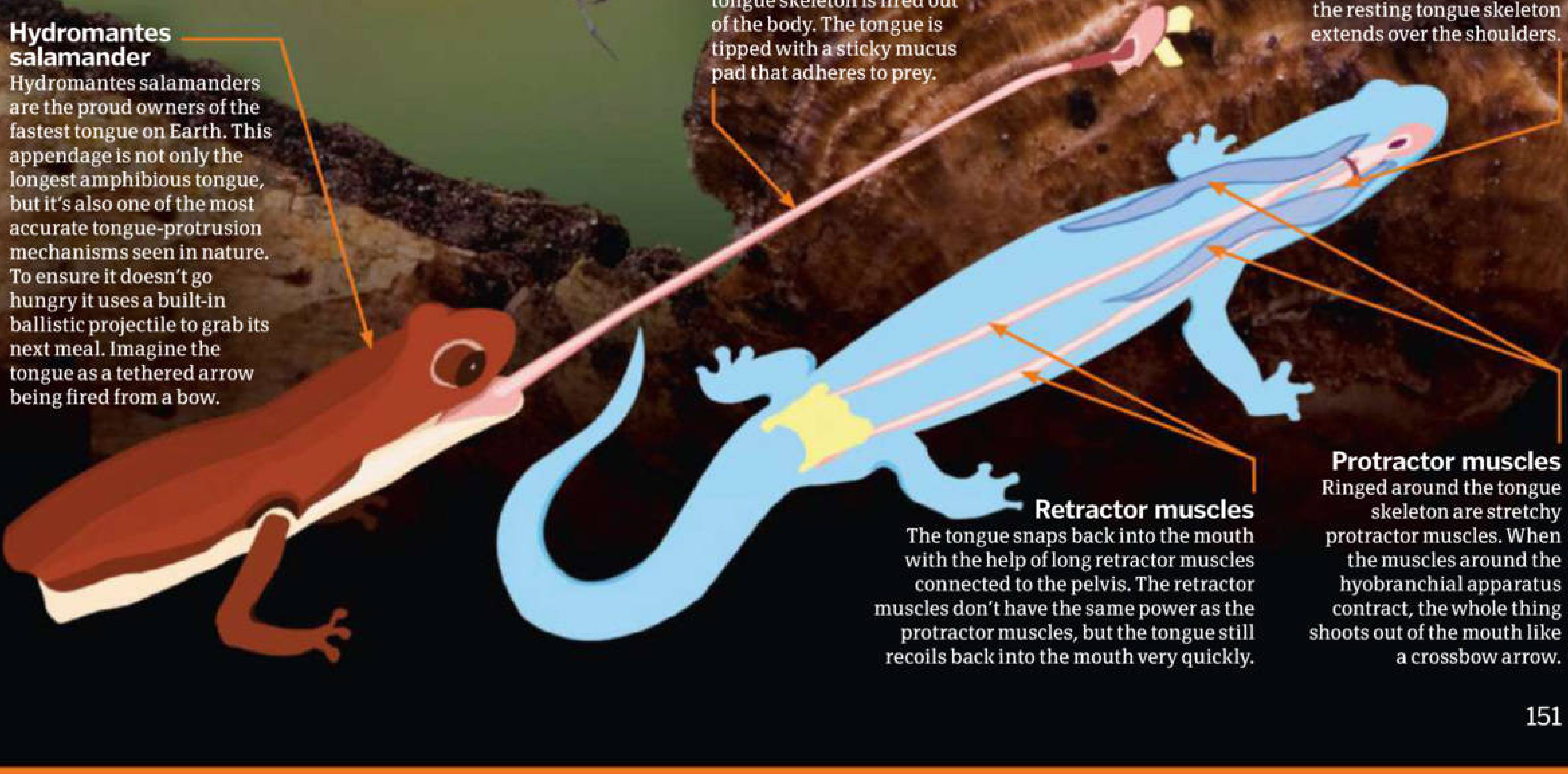
Imagine if your tongue was 80 per cent of the length of your body, and you could poke it out and then reel it back in again within 20 thousandths of a second. Well, if you're a lungless Hydromantes salamander that's one ability you already possess.

Creatures like frogs, chameleons and salamanders have a staple diet consisting mainly of insects. In order to make a quick getaway, most of these bugs have evolved sensors that detect even the slightest movements made by their would-be assassins, so the hunter must be able to get close without being detected. To help them grab a bite, some amphibians and reptiles have very long and sticky tongues – perfect for catching flighty prey without having to get so close. While most of these animals strike out using elastic recoil, Hydromantes do things a little differently...

The tip of the chameleon's ballistic tongue can accelerate up to 50 g – five times faster than a fighter jet!

The fastest tongue in the world

See how the web-toed salamander uses ballistics to fire its entire tongue skeleton out of its body



Hydromantes salamander
Hydromantes salamanders are the proud owners of the fastest tongue on Earth. This appendage is not only the longest amphibious tongue, but it's also one of the most accurate tongue-protrusion mechanisms seen in nature. To ensure it doesn't go hungry it uses a built-in ballistic projectile to grab its next meal. Imagine the tongue as a tethered arrow being fired from a bow.

Projectile
The tongue exploding from the mouth is truly projectile in the sense that the entire tongue skeleton is fired out of the body. The tongue is tipped with a sticky mucus pad that adheres to prey.

Tongue skeleton
The tongue consists of a bony skeleton surrounded by protractor muscles that store elastic energy. While the tongue skeletons of other amphibians are found in the base of the mouth, in this lungless salamander species the resting tongue skeleton extends over the shoulders.

Retractor muscles
The tongue snaps back into the mouth with the help of long retractor muscles connected to the pelvis. The retractor muscles don't have the same power as the protractor muscles, but the tongue still recoils back into the mouth very quickly.

Protractor muscles
Ringed around the tongue skeleton are stretchy protractor muscles. When the muscles around the hyobranchial apparatus contract, the whole thing shoots out of the mouth like a crossbow arrow.

© Thinkstock; Patrick Coin

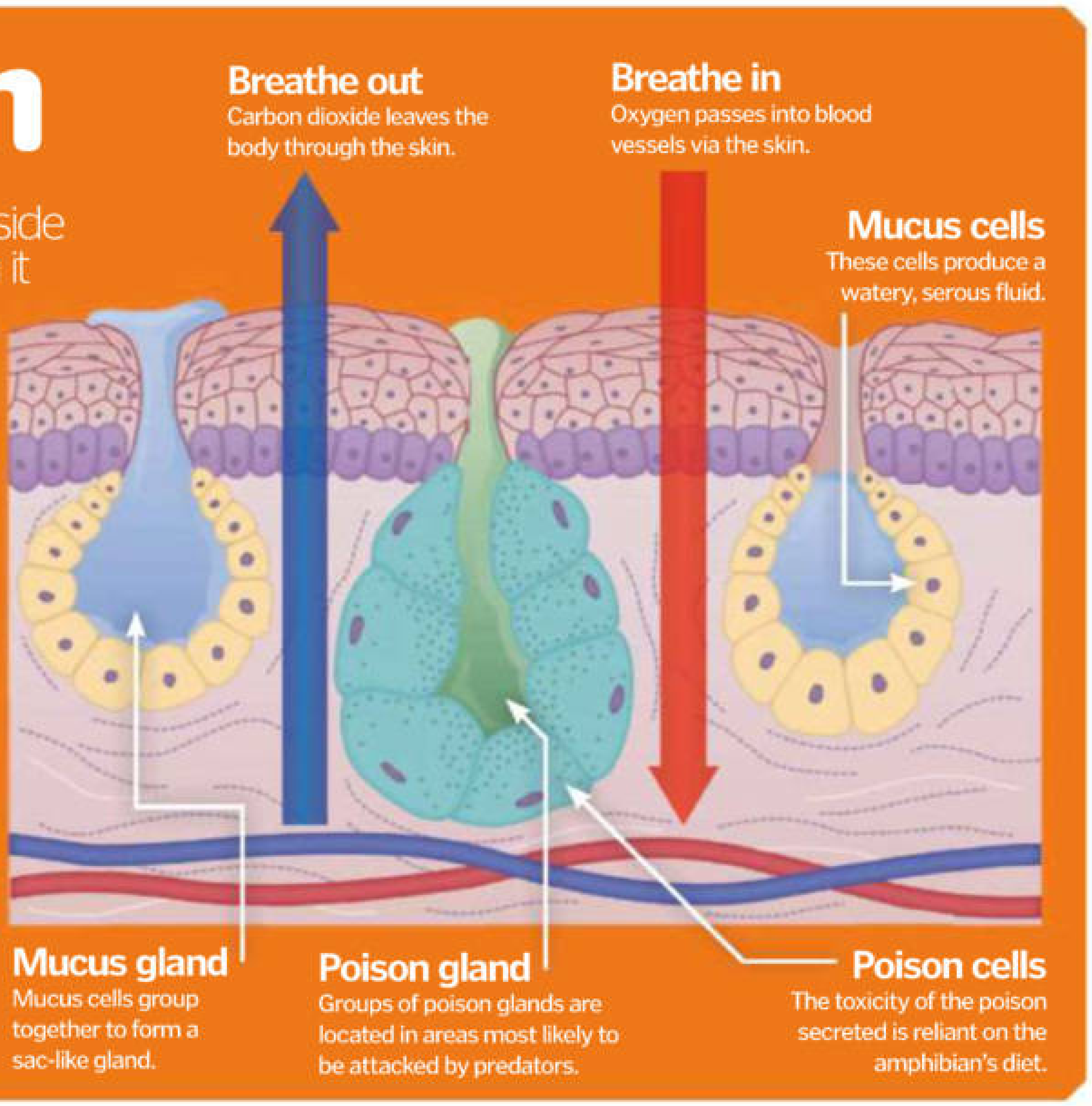
Amphibian skin

Skin is the body's main protective barrier against the outside world, and although an amphibian's skin is only very thin it has many qualities vital to keeping amphibians alive

Amphibians can breathe in and out through their skin – on land and under water – and they take in water not through their mouths but instead through absorbent skin on their underside called a seat patch. Most adult amphibians have lungs, but additional oxygen is taken in through the skin. Some species of salamander have no lungs or gills at all, and just breathe exclusively through their skin.

The reason amphibians feel slippery is that their skin is full of glands that produce mucus, which spreads across the surface of the skin. This mucus moistens the skin, making it softer and therefore more oxygen absorbent. Although amphibians have few defences against predators, they do have additional poison glands on their skin that secrete irritating toxins for repelling would-be diners. Most are only mildly poisonous, but some species, such as the poison dart frog, are deadly to the touch.

Amphibian skin must stay moist to prevent the body from becoming too hot or cold, and also to avoid desiccation (drying up), which spells the end for Mr Toad. This constant need for moisture means that, as well as producing mucus, amphibians should live close to a water source.



Breathe out
Carbon dioxide leaves the body through the skin.

Breathe in
Oxygen passes into blood vessels via the skin.

Mucus cells
These cells produce a watery, serous fluid.

Mucus gland
Mucus cells group together to form a sac-like gland.

Poison gland
Groups of poison glands are located in areas most likely to be attacked by predators.

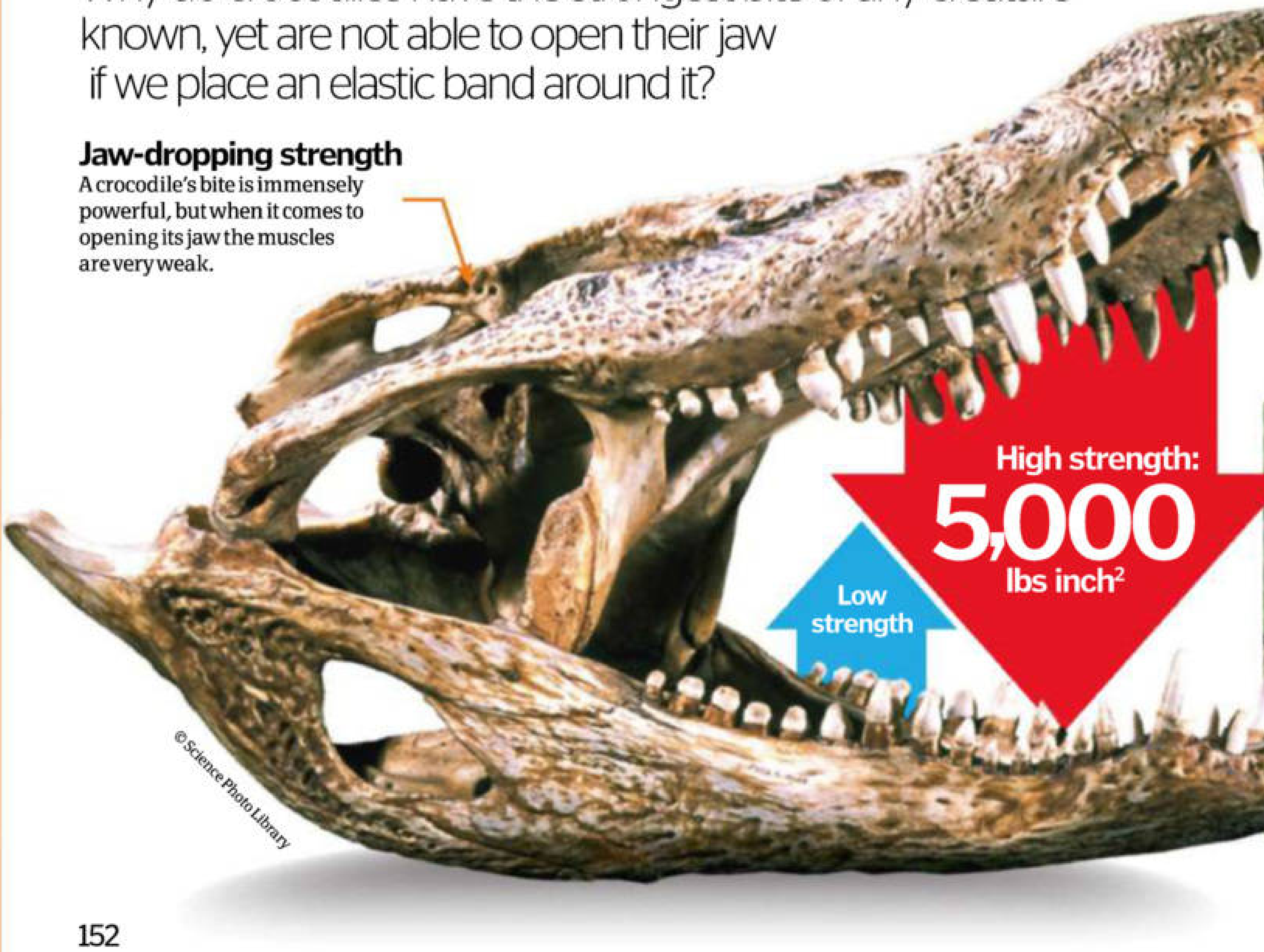
Poison cells
The toxicity of the poison secreted is reliant on the amphibian's diet.

Crocodile jaw

Why do crocodiles have the strongest bite of any creature known, yet are not able to open their jaw if we place an elastic band around it?

A crocodile has the strongest bite of any known creature, producing a force of around 5,000 pounds per square inch. The muscles that control this bite down have evolved and developed to be extraordinarily strong, and alongside relative speed over short distances on land and the immensely sharp teeth that crocodiles prominently display, this forms an immense weapon for the crocodiles to successfully hunt within a competitive environment.

However, although the jaw muscles used to snap the jaw shut are well developed, the muscles used to open the jaw are considerably weaker, so much so that if the jaw is taped shut or a large rubber band is put around it, the muscles are not strong enough to push up against the force created by these.



Jaw-dropping strength
A crocodile's bite is immensely powerful, but when it comes to opening its jaw the muscles are very weak.

© Science Photo Library

That's one snappy smile!

© Siarvan Schalkwyk

Death rolls

How crocs employ this tactic

Commonly misunderstood, the crocodile death roll is a unique method to feed off previously killed prey, not a method to kill them. The most famous user of the death roll is the Nile species of crocodile, common to the Nile River in Egypt. Here, crocodiles use their camouflage and speed to grab large prey and drag them into the water. Once there, the crocodile proceeds to drag the target underwater, holding it there until it drowns. Once the prey is dead, the crocodile then performs the death roll in order to tear large chunks of flesh off its body quickly and efficiently. To do this, it buries its large teeth into the creature's flesh, before rolling its body 360 degrees. The muscular force of the crocodile's body in partnership with the sharpness of its teeth proceed to tear the prey open, something that would prove difficult within the water while stationary.

Marsh crocs basking in the sun

© Kmanroj

A close-up view of a snake's shedded skin

© Mylittlefinger

Why do snakes shed their skin?

How and why do these slippery reptiles moult so frequently?

Snakes shed their skin for two main reasons. The first is to facilitate continued growth. This occurs as snakeskin does not grow in partnership with the snake itself, unlike in humans, where millions of skin cells are shed each year continuously on a microscopic, unseen level. On the contrary, snakes cannot shed skin in this microscopic way, necessitating them to literally outgrow the outer layer of skin whole on a frequent basis. The frequency that snakes shed their skin is largely dependent on the stage of life cycle they are in, with sheddings incredibly frequent during infancy and teenage years (bi-monthly in some species), but slowing to a couple of times per year as adults.

The second reason why snakes shed their skin is to preserve their health. Poor living conditions (lack of humidity, lack of vegetation, excess heat, and so on) as well as an inadequate food source can lead to skin damage and parasites. If left unchecked for a long period of time in the wild, this would be highly detrimental to the snake's well being. By shedding its skin, the snake can mitigate these potentially damaging conditions and start anew with fresh skin.

Interestingly, however, the shedding process brings with it complications. For the week or two preceding the shedding, the snake's vision is impaired due to the loosening of the skin's outer layer, and the week or two after the event, the new outer layer is soft and vulnerable to attack from predators. For this reason, snakes tend to be overly protective around sheddings, and largely inactive if possible. The snake initialises each shedding by rubbing itself against a sharp object such as rock, to pierce the outer layer of skin.

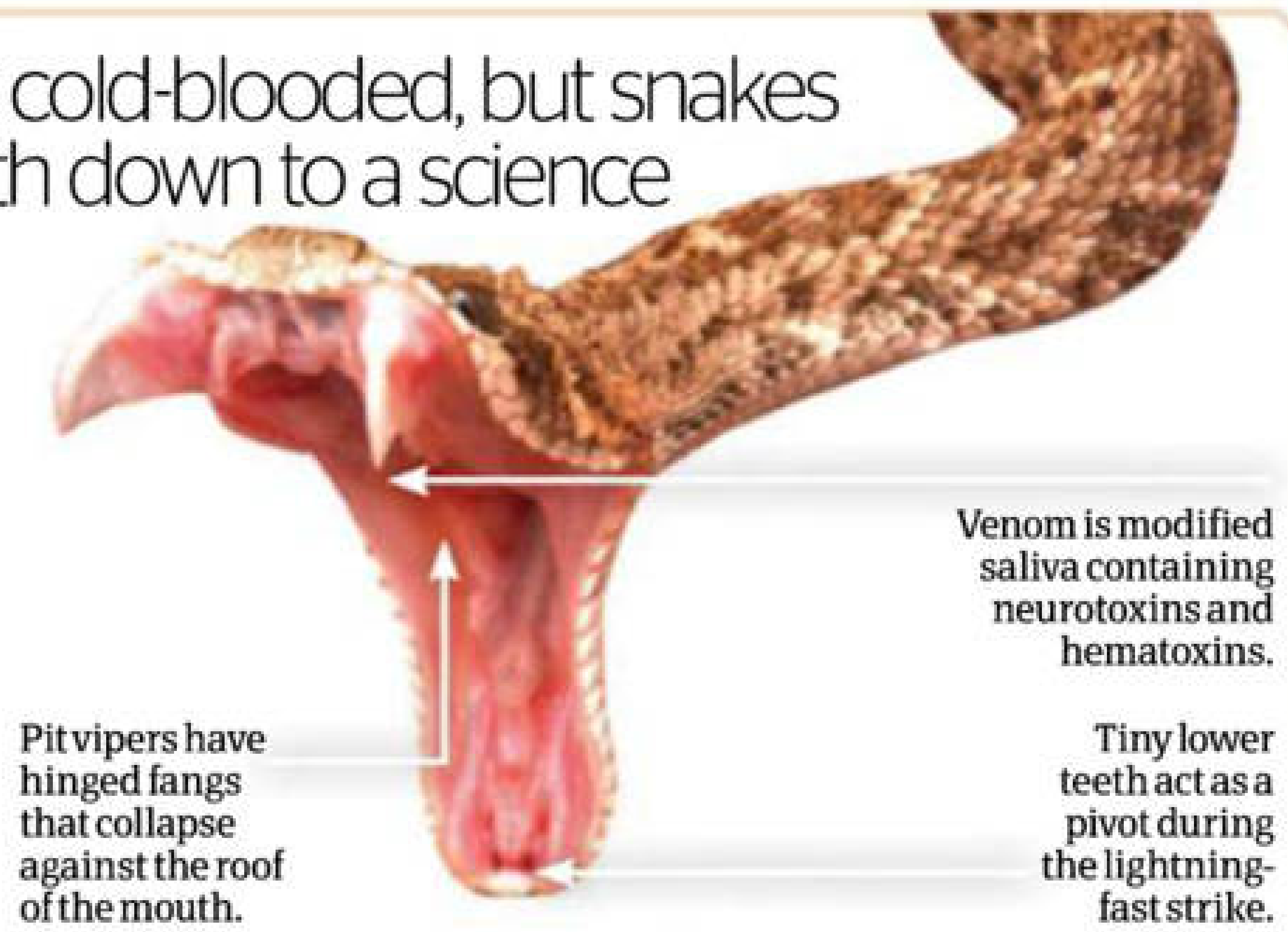
How do snakes bite?

Call them cold-blooded, but snakes have death down to a science

Snakes are highly adapted killers. Non-venomous snakes kill by constriction (suffocation) or swallowing prey alive. Venomous snakes – which make up only ten per cent of the world's snake species – inject their victims with powerful toxins that either paralyse the respiratory system or attack red blood cells, instantly rotting flesh and bone.

Only venomous snakes have fangs, a set of long, hollow teeth in either the front or back of the mouth that act as hypodermic needles. As fangs enter the flesh, the snake flexes its jaw muscle, squeezing toxic saliva out of the venom gland, through the fang's venom canal and deep into the victim's tissue.

Snakes can control the release of venom, so many defensive strikes against humans are non-lethal 'dry bites'. If bitten, never try to cut open the wound or suck out the venom. Keep the victim calm and get to a hospital quickly for a dose of antivenin.


Venom is modified saliva containing neurotoxins and hematoxins.

Pit vipers have hinged fangs that collapse against the roof of the mouth.

Tiny lower teeth act as a pivot during the lightning-fast strike.

How whales communicate

Whales produce a wide range of complex sounds through differing techniques

Whales communicate by creating sounds through methods that differ depending on their family type. Toothed whales – which include dolphins – produce high-pitched sounds by the manipulation of air stored in their head through their phonic lips, a structure loosely akin to the human nasal cavity. As air is passed through the phonic lips they contract, causing vibrations in the surrounding tissue before being consciously streamed by the whale.

Baleen whales differ in their sound creation, as they do not posses a phonic lip structure, doing so through manipulation of air passing through their larynx instead. The larynx works through the vibrations of internal vocal cords when air is passed over them. However, mystery shrouds this method of communication as baleen whales lack vocal cords, so presently scientists are unsure as to the exact manner in which their low-pitched sounds emanate from their larynx.

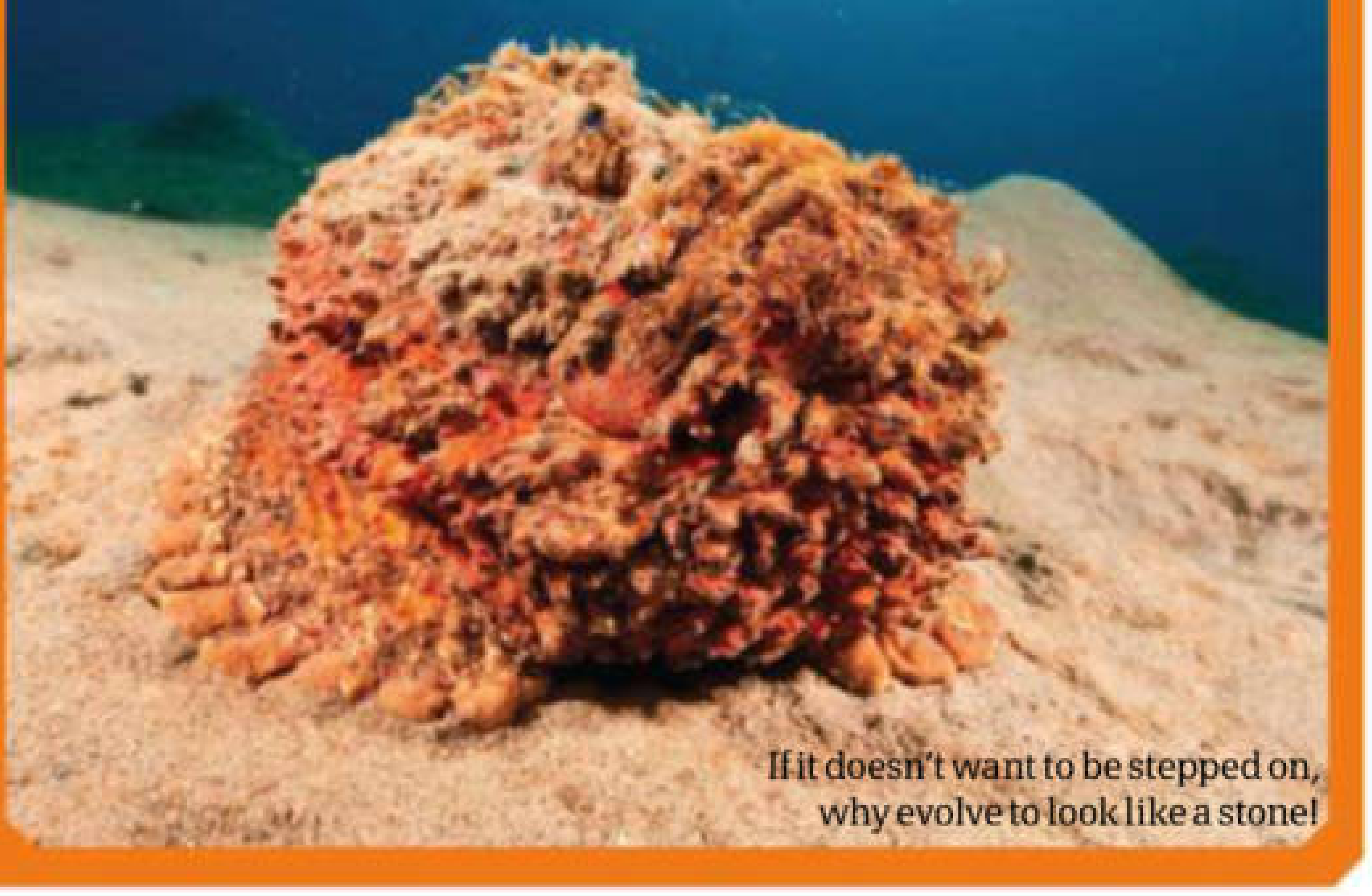
The world's most venomous fish

Almost invisible among the coral reefs, the Stonefish is a real-life killer

The Stonefish is the world's most venomous fish thanks to its ability to inject deadly neurotoxins from the spines on its dorsal fin into its target. The Stonefish's neurotoxins work by attacking the nerve cells of whatever it is injected into, causing severe pain, sickness, nausea, paralysis and, depending on depth of spine penetration into skin, death within three hours.

Unlike most other poisonous fish who dwell in the dark depths of the ocean – leaving little chance of human contact – Stonefish dwell in shallow waters and are likely to be found anywhere between just beneath the surface down to a depth of three metres.

> "The Stonefish's neurotoxins work by attacking nerve cells"

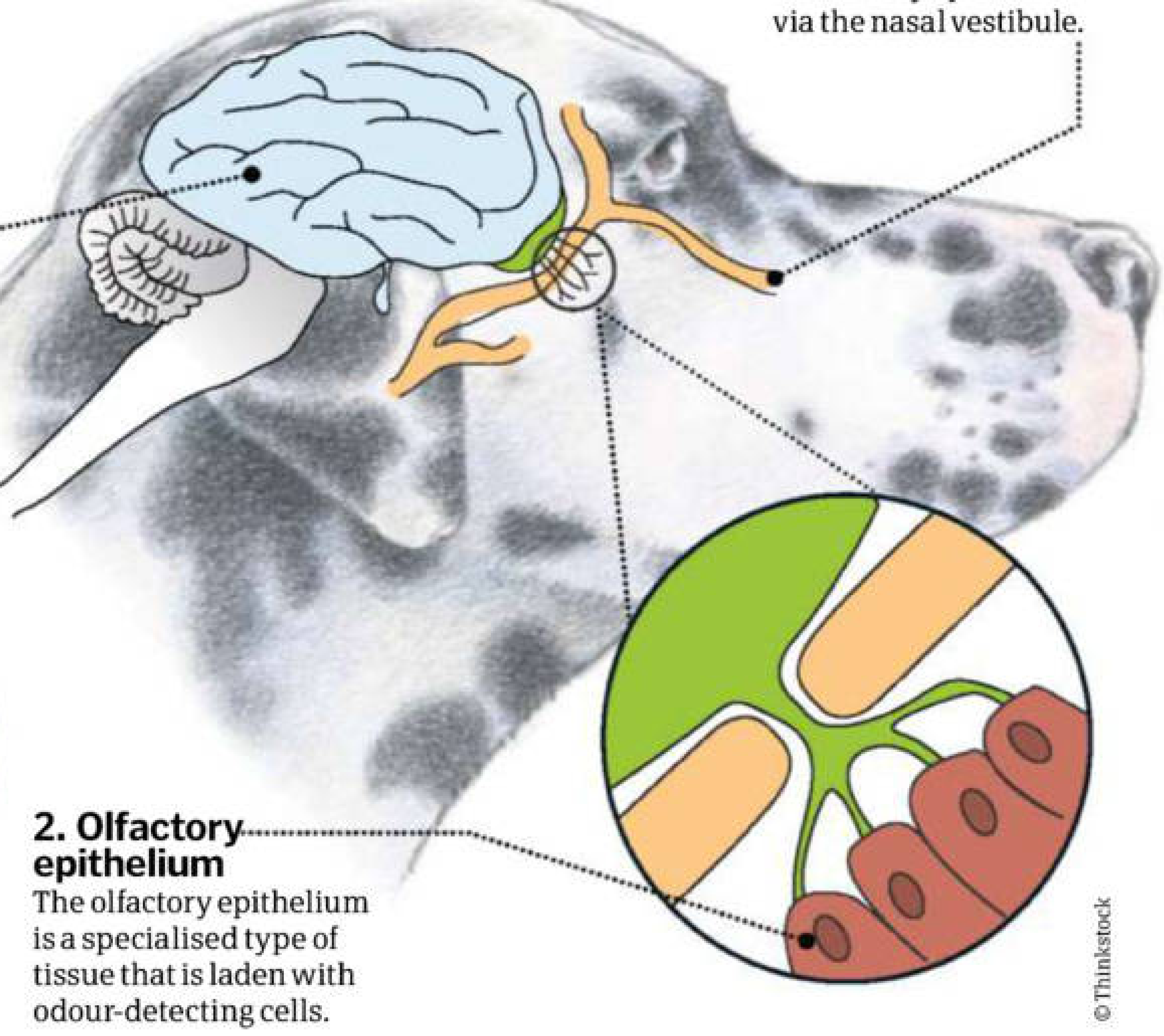


If it doesn't want to be stepped on, why evolve to look like a stone!

How do dogs smell?

Ever wondered why canine noses are so good at finding food? We sniff out the answer

Man's best friend is famous for its sense of smell. In canines this consists of a nasal vestibule and olfactory epithelium. The former channels odour-rich particles to the latter, with the epithelium supporting millions of receptor cells that absorb the odour's chemical composition patterns and then transports them to the brain for interpretation. Indeed, an average dog's nose has so many olfactory receptors that its sense of smell is 1,000 times more acute than ours. And why are dog noses wet? Well, they generally have damp snouts for two reasons. Firstly, a wet nose is better for smelling. The moisture comes from a layer of mucous that thinly covers the surface, trapping and soaking up scent particles. The dog can therefore naturally sniff in the smell as it radiates off the nose, or lick it to taste the odour. The second reason is that it is one of the few parts of the body where dogs can excrete sweat.



1. Nasal vestibule
Odour particles sniffed into the nose are transported to the olfactory epithelium via the nasal vestibule.

2. Olfactory epithelium
The olfactory epithelium is a specialised type of tissue that is laden with odour-detecting cells.

3. Brain
Odour patterns detected by the olfactory epithelium are transported via a sub-series of cells and nerves to the nearby brain where they are processed..

© Thinkstock

How do vampire bats survive?

Discover how these flying mammals get by on a diet consisting solely of blood

In the realm of books and movies, vampires are big business, but the natural world can boast the real thing. Found across the tropical forests of South America through to Mexico, much like its fictional counterpart, the vampire bat sleeps during the day – usually in dark caves – and only ventures out at night to feed.

Their most common unwitting 'donors' are large herbivores like horses and cows, though human attacks are not unheard of. Most of the time, victims will rarely notice as the bats only consume about a tablespoon of blood per sitting; this said, they are often accused of spreading rabies. Contrary to popular belief, they don't actually 'suck' the blood either, but rather nip the skin with their sharp teeth and then lap at the blood that flows out.

Like all bats they use echolocation to get around, but they have also evolved some unique ways to hunt. For one thing they have special thermoreceptors on their noses, which – via infrared radiation – enable them to pinpoint where blood flows closest to the prey's skin, while an anticoagulant in their saliva stops blood clotting before they've had their fill. Vampires are also unusual within the bat family for their ability to walk, climb and even hop along the ground – ideal for stealthily approaching their unsuspecting victims.

Vampire bats live in dark caves typically in colonies of around 100

© Thinkstock

UNDERWATER WONDERS

Real-life sea monsters so gigantic they dwarf the dinosaurs

The open ocean is an extremely dangerous place to live. There are no trees to hide in, no burrows you can dig. Death surrounds you in three dimensions and everything larger than you is a predator. To survive, you have to think big. For some species, this means living as part of a large school of fish. For others, it means actually becoming genuinely, truly enormous. Tiny fish are eaten by small fish. Small fish are eaten by larger fish and so on. In every size bracket, natural selection favours the larger animal over the smaller one. Over millions of years, animal species tend to grow gradually larger and larger until they are too big to fit in anyone's mouth.

Being big is easier in the sea than on land because the buoyancy of water supports an animal evenly around its body, instead of just through the soles of its feet. An African elephant, for instance, can't grow much larger than ten tons without fracturing its own legs. A blue whale, meanwhile, will weigh this much before it's three months old.

Sea giants can get by with much smaller skeletons and their bones don't need to be so strong as they aren't subject to so much shock loading. But the density of water also presents some challenges. It's much harder to move through water than air, so streamlining is essential. A blue whale is 60 times longer than it is wide, compared with only 3.5 times for a hippo. The rear third of the whale's body provides the muscle to drive the 7.5-metre (25-foot) tail fluke up and down. Why does an animal with no natural predators need to cruise at 32 kilometres (20 miles) per hour? One reason is that it makes it much harder for barnacles to attach. It's ironic that an animal as large as a whale should be threatened by something as small as a barnacle, but if enough take hold, the extra drag drastically increases the energy required to swim.

Food is the limiting factor for all big sea creatures. Light doesn't penetrate far in water so there are no grassy plains for large herbivores to graze. Instead the ocean is a thin soup, with the occasional chunk of meat bobbing in it. You can chase after the chunks, but catching them requires more energy, which means you need more food and so on.

The largest animals in the sea have found it is more lucrative to swallow the 'soup' instead. This is a mixture of unicellular organisms, fish larvae and shrimp, ie plankton. They are too small to swim against the current, so it's just a matter of straining them from the water. The lion's mane jellyfish can do this while expending virtually no energy. It swims slowly up by pulsing its bell and then relaxes

Blue whale

The largest animal ever to have lived

Binomial name: Balaenoptera musculus

Type: Mammal

Diet: Filter feeder, eg krill, copepods

Average life span in the wild: 80 years

Weight: 180,000kg (396,832lb)

Size: 30m (98ft)

Worldwide distribution: Throughout the world's oceans, in five to seven main populations

Amazing fact: A newborn blue whale is the same size as an adult hippopotamus at 2.7 tons. They drink 400l (700 pints) of milk every day and put on 90kg (198lb) a day for their first seven months.

1 blue whale = 36 African elephants

Japanese spider crab

Claws that can straddle a car

Binomial name: Macrocheira kaempferi

Type: Crustacean

Diet: Carnivore, eg shellfish and carrion

Average life span in the wild: 80 years

Weight: 19kg (42lb)

Size: 3.8m (12.4ft) claw to claw

Worldwide distribution: Southern coast of Japan

Amazing fact: Those huge legs are quite fragile; almost three-quarters of Japanese spider crabs have a missing leg. This isn't a problem as they can survive with three missing, and the walking legs can grow back when the crab moults to a new carapace.

1 Japanese spider crab = 1 child

Lion's mane jellyfish

A tangled cloud of floating stingers

Binomial name: Cyanea capillata

Type: Scyphozoan

Diet: Carnivore, eg plankton, small fish

Average life span in the wild: 1 year

Weight: 25kg (55lb)

Size: 2.5m (8.2ft)-diameter bell; 30m (98ft)-long tentacles

Worldwide distribution: Arctic, north Atlantic and north Pacific

Amazing fact: The largest known lion's mane jellyfish washed up in Massachusetts Bay, USA, back in 1870. Its tentacles were 36m (118ft) long, making it longer than a blue whale and possibly the longest recorded animal.

1 lion's mane jellyfish = 1 child

to drift down again like a parachute. As it does, its tentacles billow out like hair to cover a wide area and prey gets speared by its stinger cells. Most large whales, along with the whale shark and the manta rays, adopt a slightly more active strategy by either swimming at speed into a dense cloud of plankton or taking huge gulps to suck them in, and then filtering them through a mesh of fibres made from modified teeth or gill bars. Different animals have different sized filter meshes that trap a particular size of plankton. Whales and whale sharks trap only the relatively large krill (a kind of shrimp) and crab larvae. A ton of krill contains about 450 thousand calories – which is about a tenth as much as a ton of chocolate – and an adult blue whale needs 3.5 tons of krill a day.

Very large animals protect their young to give them time to grow big enough to fend off predators. Whales are mammals so the embryo develops inside its mother to protect it. Great white sharks and manta rays have abandoned the usual fishy strategy of laying eggs on the seabed and copied mammals; the eggs are retained inside the female and hatch as live 'pups'. The mating and birthing of the whale shark has never been seen, but they are believed to use the same technique. Even the giant Pacific octopus will guard her nest of eggs until they hatch. Her month-long vigil is the last thing she does though because the exertion kills her – but she lays around 100,000 eggs in one go to compensate!

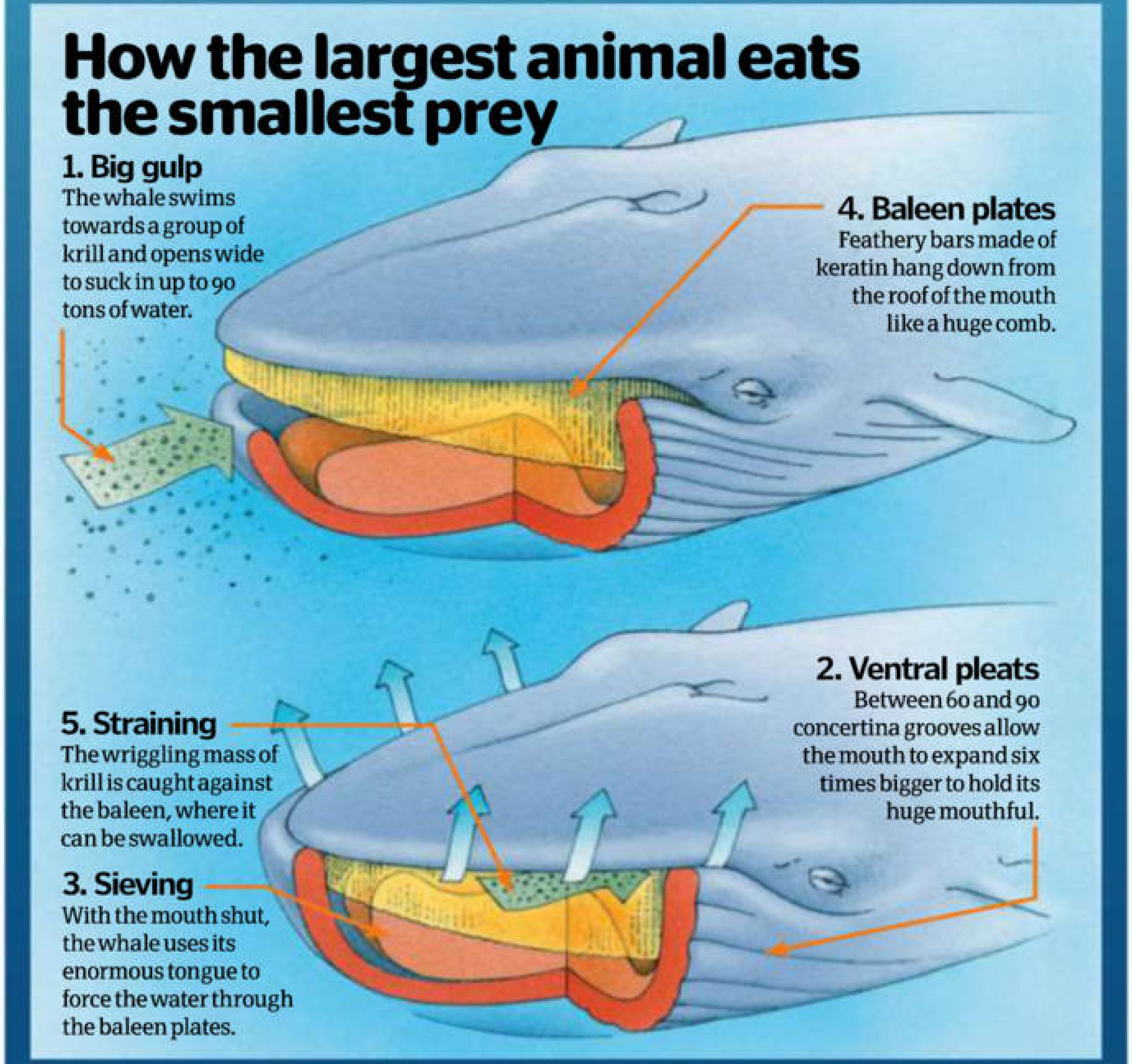
Huge fish have other tricks normally reserved for mammals too. Large sharks and manta rays have a low surface area compared to their body size so they don't lose as much heat. This makes them effectively warm-blooded and allows them to maintain a more active lifestyle even in colder seas.

The best-studied ocean giants are those that live in fairly shallow water – above 200 metres (656 feet) – where most of the plankton is. But there are very large animals including squid that live in the perpetual blackness beyond. If you are an air-breathing mammal like a sperm whale that feeds on these squid, you face a unique challenge. To feed you need to dive to depths of up to three kilometres (1.9 miles), but to breathe you need to return to the surface. The pressure change in a round-trip is almost 300 atmospheres! To cope with this, sperm whales have three times more myoglobin in their muscles to store more oxygen and their ribcage is flexible so that the lungs collapse under pressure and reduce the amount of nitrogen that dissolves into the blood. Despite this, the skeletons of older whales show pitting from the decompression effects of repeated dives.

Supersized diets

Large animals have big appetites. Exactly how big depends on how fast you burn energy. At the bottom of the scale are the invertebrates. Jellyfish can grow to be huge, but their body is about 95 per cent water and they move very slowly. Eating just 0.04 per cent of their body weight is enough to sustain them. Blue whales, at the other end of the scale, have a warm-blooded body to support as well as a complex brain. But the hungriest creatures in the ocean are the killer whales. Their extremely active, predatory lifestyle means they need 3.7 per cent of their body weight each day to survive; when your body weighs six tons, that's a lot of fish!

How the largest animal eats the smallest prey



1. Big gulp The whale swims towards a group of krill and opens wide to suck in up to 90 tons of water.

4. Baleen plates Feathery bars made of keratin hang down from the roof of the mouth like a huge comb.

5. Straining The wriggling mass of krill is caught against the baleen, where it can be swallowed.

2. Ventral pleats Between 60 and 90 concertina grooves allow the mouth to expand six times bigger to hold its huge mouthful.

3. Sieving With the mouth shut, the whale uses its enormous tongue to force the water through the baleen plates.

How much do they eat a day?

...and how many cheeseburgers would that equate to?

Blue whale: 3,600kg (7,937lb) eg krill = 16,667

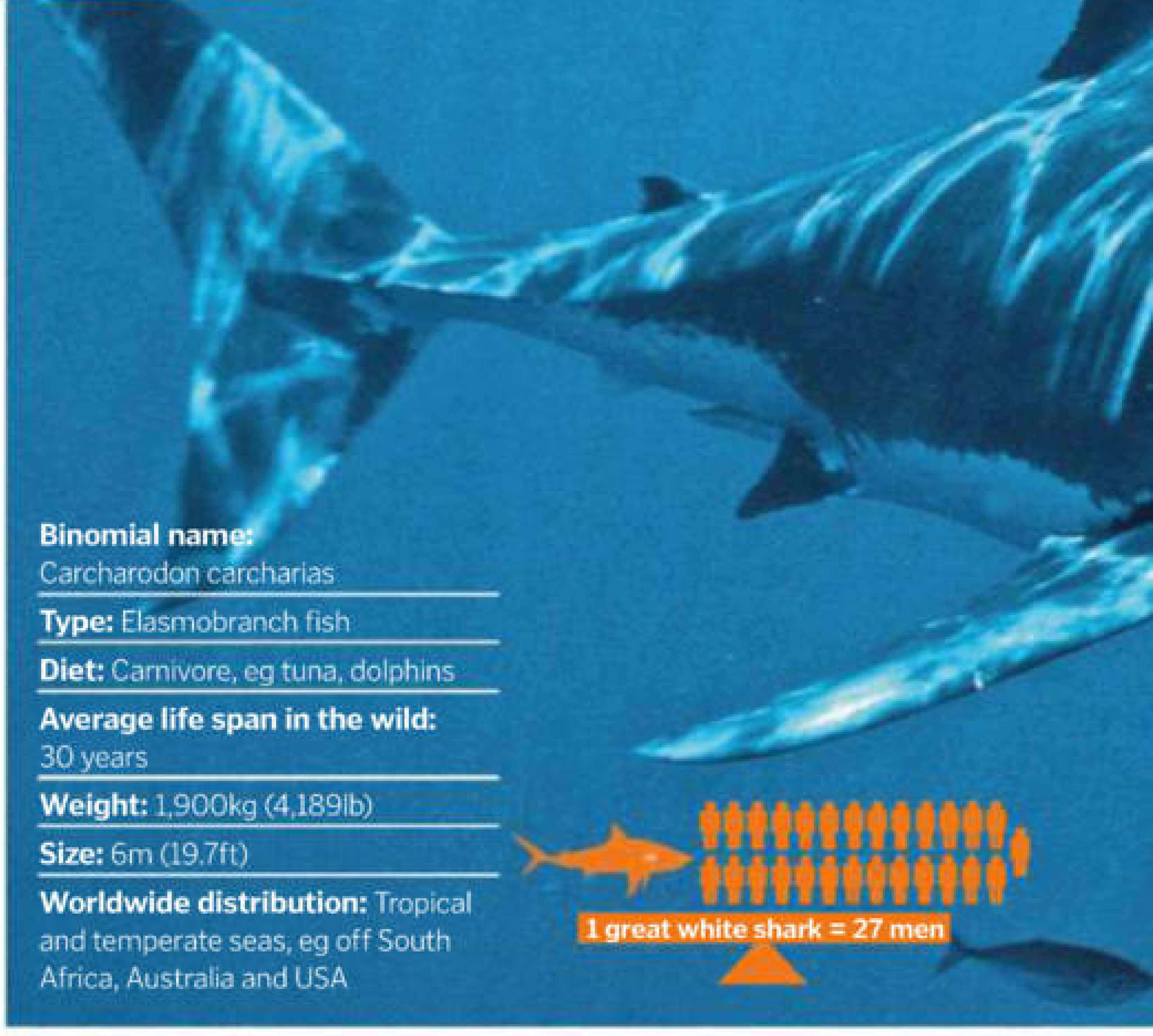
Killer whale: 227kg (500lb) eg fish, sharks = 1,051

Great white shark: 30kg (66lb) eg fish, seals = 138.9

Giant Pacific octopus: 1kg (2.2lb) eg crabs = 4.6

Lion's mane jellyfish: 100g (3.5oz) eg plankton = 0.46

The shark with the biggest bite



Binomial name: Carcharodon carcharias

Type: Elasmobranch fish

Diet: Carnivore, eg tuna, dolphins

Average life span in the wild: 30 years

Weight: 1,900kg (4,189lb)

Size: 6m (19.7ft)

Worldwide distribution: Tropical and temperate seas, eg off South Africa, Australia and USA

Each arm is as long as you are

Giant Pacific octopus

Binomial name: Enteroctopus dofleini

Type: Cephalopod

Diet: Carnivore, eg fish, molluscs

Average life span in the wild: 3-5 years

Weight: 15-70kg (33-154lb)

Size: 4.3m (14.1ft) arm span

Worldwide distribution: Coastal waters of the north Pacific

Amazing fact: Size alone isn't enough to protect this octopus. Seals, sperm whales and even sea otters all prey on them. Their short life span is an adaptation to compensate high predation. All their energy is expended in a single spawning of 100,000 eggs.

Super-smart king of the gliders

Giant oceanic manta ray

Binomial name: Manta birostris

Type: Elasmobranch fish

Diet: Filter feeder, eg plankton, shrimp

Average life span in the wild: 27 years

Weight: 1,300kg (2,866lb)

Size: 6.7m (22ft)

Worldwide distribution: Shallow water of the western Pacific and Indian Ocean

Amazing fact: Manta rays may be the most intelligent of the sharks, rays and skates, as their brain-to-body ratio is much higher than other fish. A network of blood vessels – the rete – keeps their brain warm.

Great white shark

Amazing fact: Great white sharks have two stomach compartments and can store food in one compartment for days or weeks without digesting it. Great whites have been found with shoes, wigs, newspapers, licence plates and even cannon balls in their stomachs.

Whale shark

The world's largest fish

Binomial name:
Rhincodon typus

Type: Elasmobranch fish

Diet: Filter feeder, eg krill, crab larvae

Average life span in the wild:
80 years

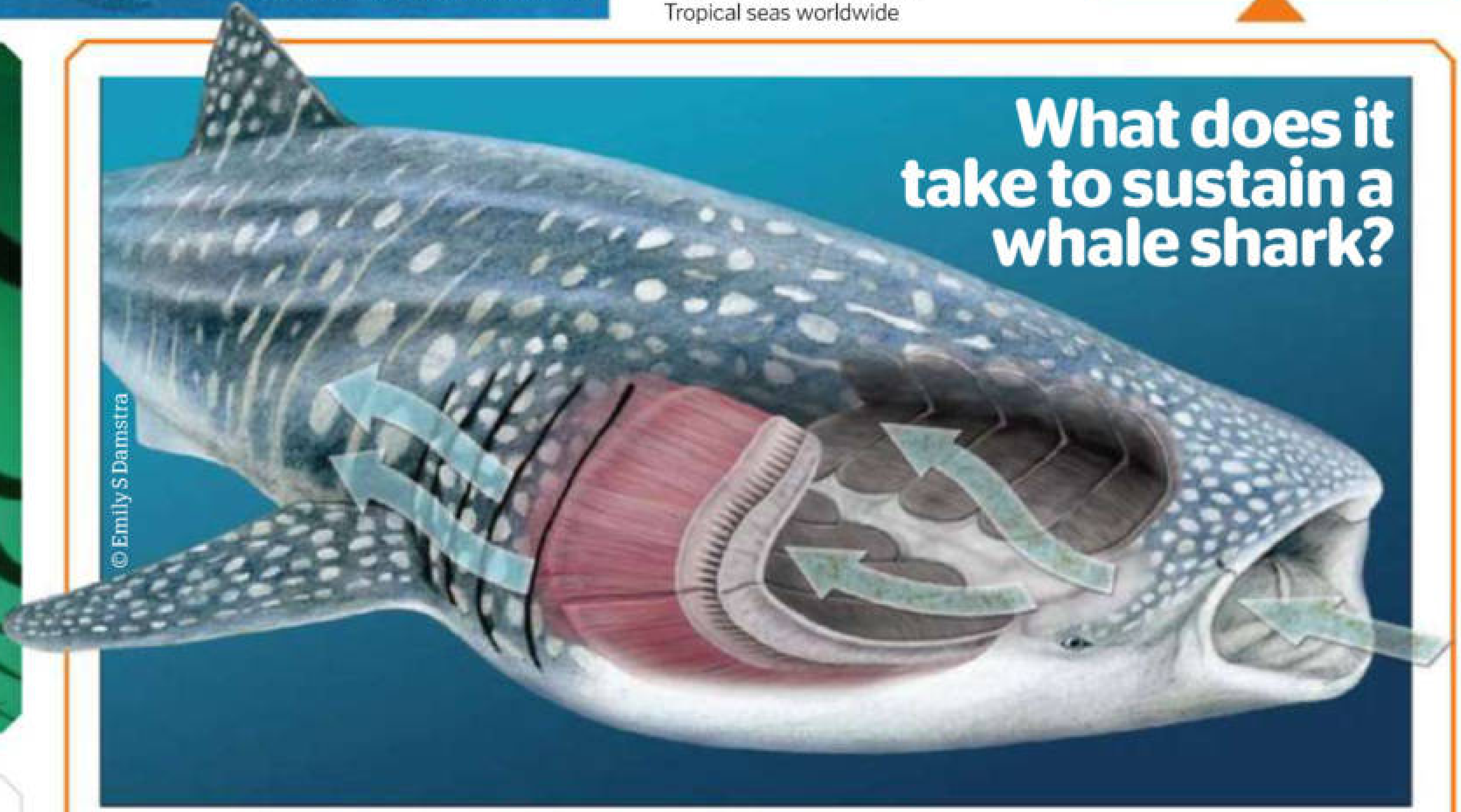
Weight: 9,000kg (19,842lb)

Size: 9.7m (32ft)

Worldwide distribution:
Tropical seas worldwide

Amazing fact: According to the Whale Shark & Oceanic Research Center, there are reports of whale sharks three or four times bigger than the norm. One caught off the coast of Taiwan in 1994 allegedly weighed almost 36 tons!

What does it take to sustain a whale shark?


© Emily S Damstra

Mouth

When a whale shark is feeding, its mouth can gape 1.5m (4.9ft) wide. This creates tremendous suction that makes it impossible for small animals to swim out of the way. Whale sharks have over 300 rows of teeth but each tooth is quite small and they don't appear to serve any purpose.

Skeleton

Sharks have cartilage rather than bone, and no ribcage. Whale sharks beached in shallow water are quickly crushed to death by their own body weight. In the open sea, though, a cartilage skeleton saves weight because it has half the density of bone. This makes the whale shark a much more efficient swimmer.

Gills

The real business of feeding occurs at the gills. As well as extracting oxygen from the water, the gills have ten filter pads (see picture) that sieve out anything over 2-3mm (0.08-0.12in). Although efficient, sometimes the pads can become blocked and the shark must 'cough' to clear them.

Skin

10cm (3.9in)-thick skin provides a rigid covering that maintains the shark's streamlined shape; when we swim, the water causes our skin to ripple, which leads to drag. Shark skin is also covered with tiny placoid scales. Each one is structured like a tooth, with enamel, dentine and a pulp cavity; the scales reduce microturbulence.

Brain

Whale sharks have quite small brains compared to other sharks. Brain tissue requires a lot of energy, so big brains must earn their keep. These sharks don't actively hunt, and their huge size keeps them safe from most predators, so they don't need the same cunning as other shark species.

Liver

Instead of a swim bladder, sharks use an oil called squalene to maintain buoyancy. This is stored in the liver and, since oil isn't as light as gas, the whale shark needs lots of it – indeed, the liver can weigh up to two tons! Fishermen in Kenya hunt whale sharks for their liver and the oil from a single shark can last them for years.

Ones that got away!

Meet a few more behemoths of the deep

Seven-arm octopus

Heavier than the giant Pacific octopus, but with shorter tentacles. It actually has eight arms altogether but keeps one coiled up out of the way, except when it's mating.

Colossal squid

Thought to grow up to 14m (45.9ft) long, an adult specimen has never been found. It has the largest eyes in the animal kingdom.

Sperm whale

This 40-ton cetacean has the largest brain of any animal ever to have lived and has teeth that weigh 1kg (2.2lb) each. Its diet includes the colossal squid.

Giant clam

The biggest bivalve mollusc. They can weigh up to 200kg (441lb) and live on a combination of filter feeding and photosynthesis from symbiotic algae.

Brisingid starfish

Midgardia xandaros is the biggest starfish. Its slender arms can be up to 1.4m (4.6ft) long. Most starfish have five arms while some, like the one pictured, have 12 or more!

Giant isopod

Bathynomus giganticus might look like a garden woodlouse, but this relative of the common critter can weigh up to 1.7kg (3.7lb) and reach 76cm (29.9in) long; that's the size of a newborn baby!

© Corbis; Thinkstock; DK Images; Getty

Life cycle of the emperor penguin

Discover the incredible endurance of Earth's biggest penguins and how they survive the bitter Antarctic

While the northern hemisphere experiences winter between December and February, winter in the Antarctic takes place between June and August. One of the only creatures to endure the -30-degree-Celsius (-22-degree-Fahrenheit) temperatures and 160-kilometre (100-mile)-per-hour winds of Antarctica's harsh winters is the emperor penguin. The stalwart males in particular spend the entire winter in the unforgiving landscape of the frozen continent's exposed open ice.

While pretty much all other Antarctic wildlife heads for milder climes, the emperor penguins stick it out. The reason they do this is so that the new chicks will be fully fledged in midsummer when survival rates are much higher.

It's a treacherous 12 months in the life of an emperor penguin, but their resilience and dedication to caring for a single precious egg for months on end is simply extraordinary.

The statistics...

Emperor penguin

Type: Bird

Genus: Aptenodytes

Diet: Carnivore, eg fish, squid

Average life span in the wild: 15-20 years

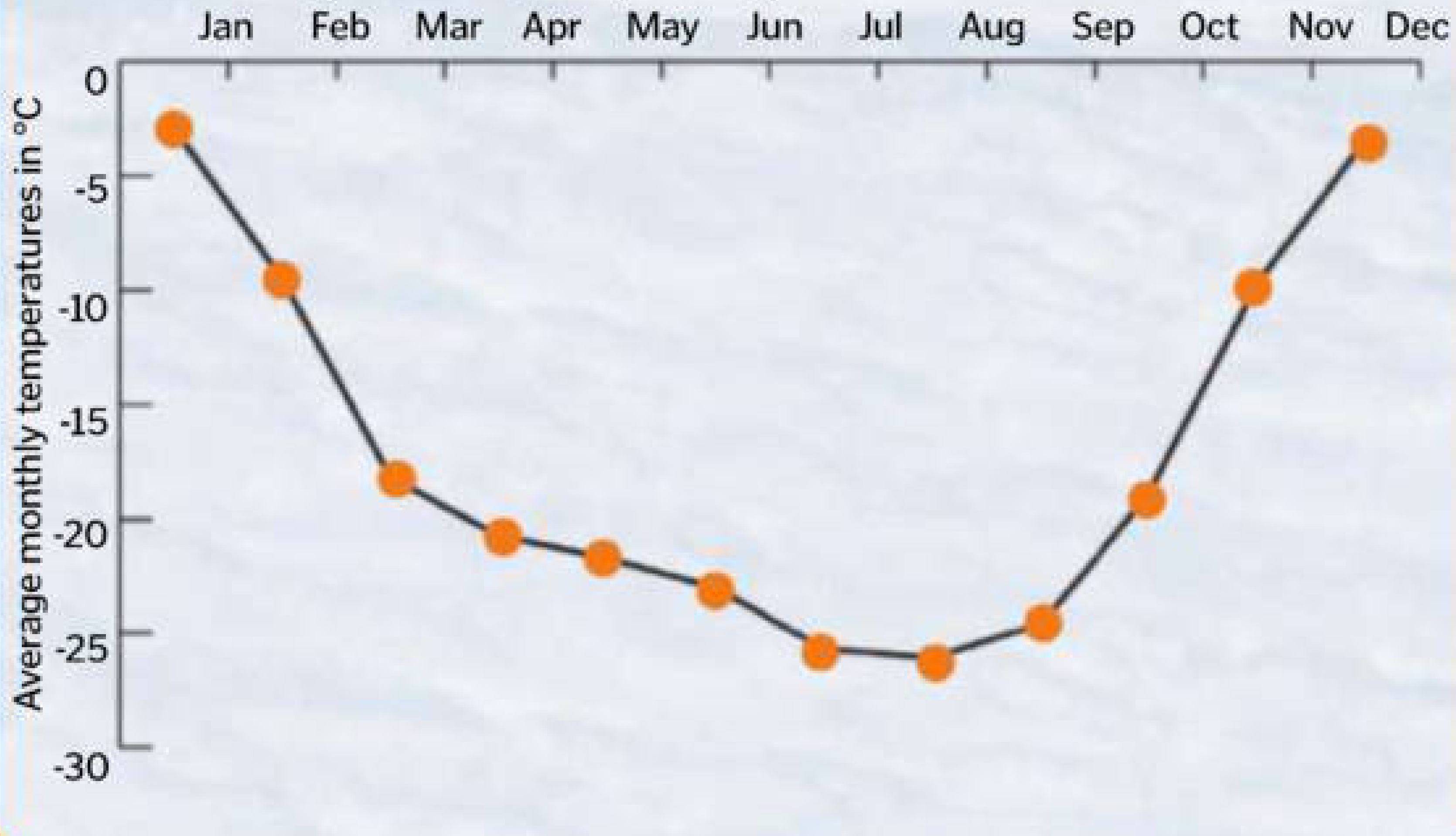
Height: Up to 130cm (51in)

Weight: 25-45kg (55-100lb)

The emperor penguin is the tallest and heaviest of all living penguin species and is endemic to Antarctica

It's cold out there...

Home to the lowest temperature ever recorded at the Earth's surface, Antarctica can get seriously chilly during winter



A year with the emperors

What goes on over the course of 12 months in a community of the planet's biggest penguins?

1 Feeding: January-February

At the start of the year, the adult emperor penguins head out to sea to feast and make the most of the more accessible food in the summer.

2 Winter draws in: March

Temperatures begin to plummet from March, and over the coming months the region will be battered by freezing winds and bitterly cold temperatures.

3 Home to breed: April

The male and female emperors return from feeding and make their way to the breeding grounds in the south of the continent. Despite the fact that a colony can contain anywhere up to 12,000 pairs about 15 per cent of couples hook up with their mates from the previous year.

4 Breeding: May

After mating, the female emperor penguins lay a single egg, which they immediately leave in the safe hands (or perhaps more accurately the 'safe feet') of their male partner. With the absence of a nest the male rests the egg on his feet beneath an insulating flap of warm, feathery skin.

5 Females feed: May

With the egg safely in the care of the males at the breeding ground the females then embark on a treacherous expedition back out to sea. They can trek around 80-160 kilometres (50-100 miles) to the edge of the ice pack in search of vital food.

6 Incubating: June-July

For nine long weeks each male alone will protect his egg in his brood pouch. During this time he will have nothing to eat and conditions on the ice will grow increasingly hostile. To conserve heat, the fathers huddle in a tightly packed group. Once the penguins on the inside of the huddle have warmed up they will migrate to the outer edge to give other penguins a chance to thaw out. It's a bit like a penguin conveyor belt.

7 Hatching: August

In August – usually before the females return home from feeding – the chicks will begin to hatch. To reduce the number of breakages, emperor penguin eggs have an extra-thick shell, which accounts for over one-sixth of the egg's weight, and it can take several days for the chick to break through. Once hatched the young penguin will maintain its position beneath the flap of skin above the adult's feet. Any unlucky chicks that fall out of the brood pouch are likely to perish within minutes because of the sub-zero temperatures.

8 Females return: September

With their stomachs full the female penguins return to the nesting ground just after the chicks have hatched. Their unique calls help them to locate their mates among the throngs of penguins. Upon being reunited with their young family they will regurgitate a meal stored in their bellies for their chicks.

9 Males feed: September

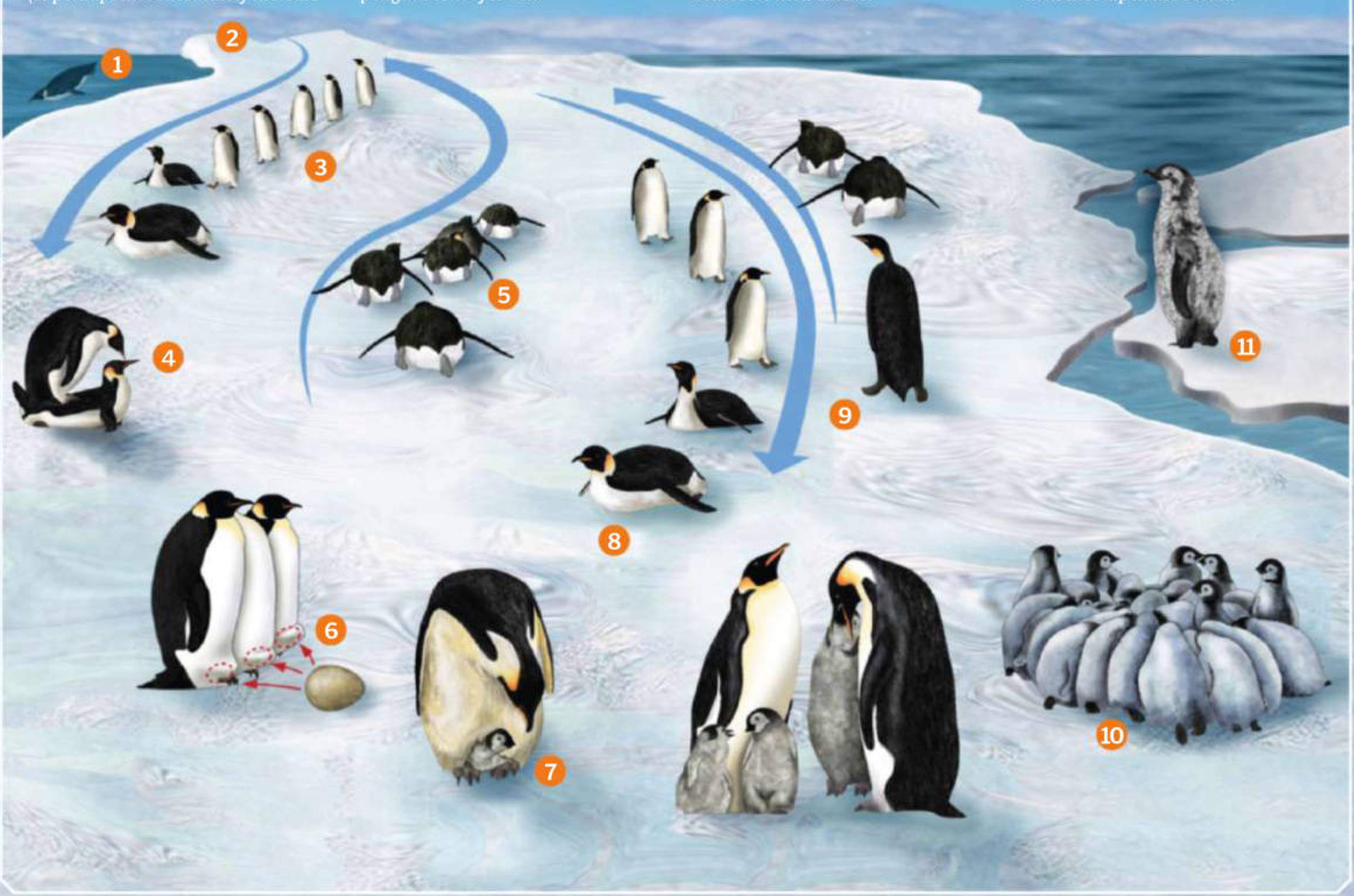
Relieved of their chick-sitting duties the male emperors head to sea to forage for themselves. Having shed up to half their body weight they are very hungry indeed. The parents then take it in turns to head off in search of food.

10 Crèches: October-November

As winter begins to subside the growing chicks will leave the warmth of their parents' brood pouches after about seven weeks. Their downy feathers will moult and their coats will eventually toughen up to form a waterproof covering. To stay warm the chicks huddle in small groups called crèches.

11 Fledged: December

The warmer weather melts the pack ice so that it breaks up into pieces, effectively bringing the sea closer to the colony. Fully fledged chicks will now rejoin their parents and take their first dip in the ocean.



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Giant pandas explained

The carnivore that thinks it's vegetarian

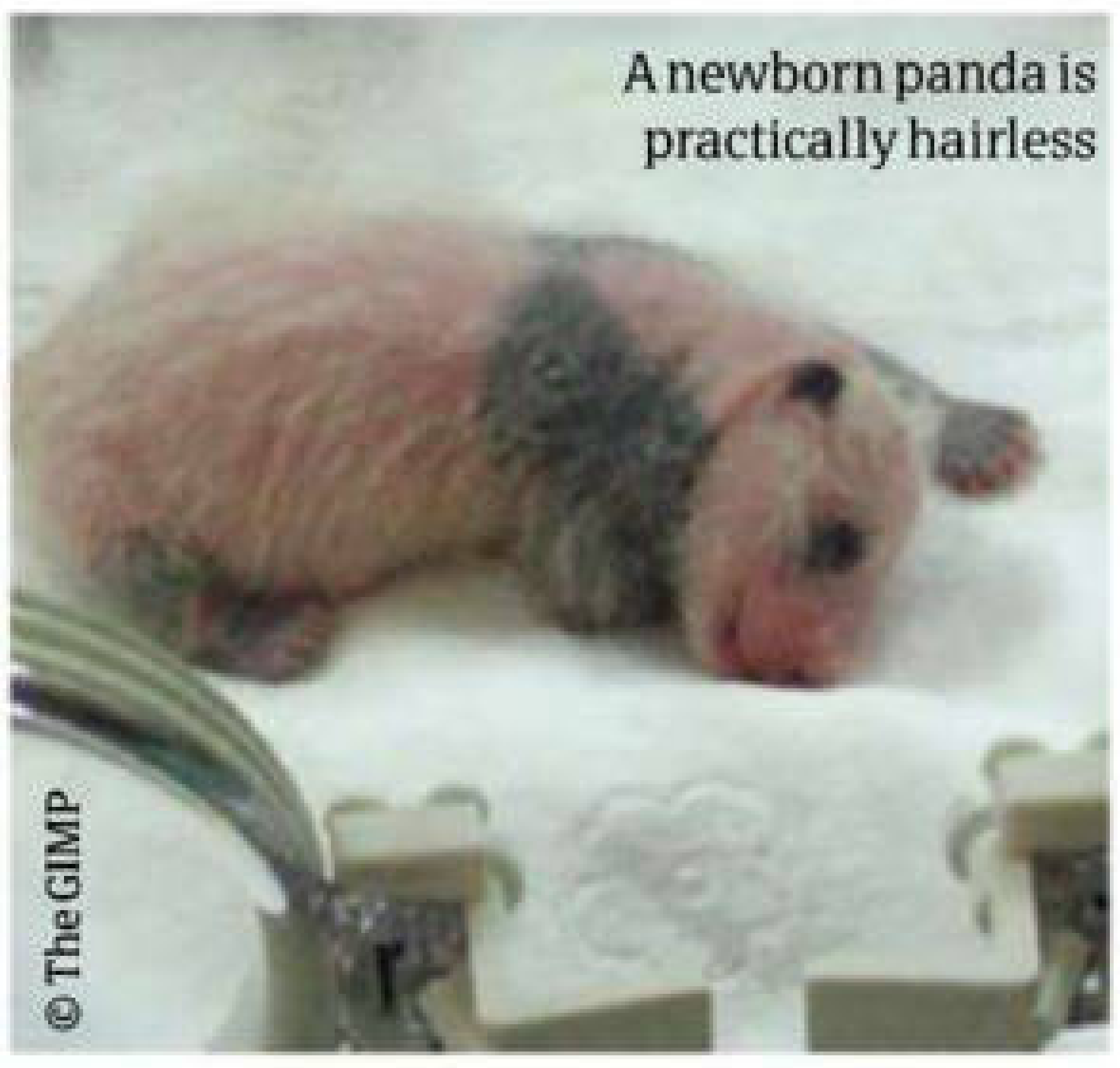
© Science Photo Library

There he sits, the giant panda. Solitary, peaceful, resting upright on his furry haunches like a black-and-white Buddha. A born carnivore, this perplexing member of the bear family passes on the meat course almost entirely, choosing to persist on nature's version of a celery diet: bamboo.

A highly endangered animal – less than 2,500 exist in the wild – the panda's monotonous (nearly monovorous) diet is part of its undoing. The nutritional value of bamboo is negligible, exacerbated by the fact that the panda is genetically incapable of digesting cellulose. The result is that much of the panda's extremely high-fibre diet passes right through it, providing only minimal calories to an animal that can grow up to 136kg (300lbs) in the wild.

So there the giant panda sits, for up to 16 hours every day, tearing and grinding away at piles of this nearly indigestible plant simply to eke out enough caloric energy to wake up the next day and do it all again. That peaceful, almost Zen-like demeanour has less to do with temperament than low blood sugar. The poor panda can hardly muster the energy to mate, and when he does successfully reproduce, the female will only raise one young at a time, even though the majority of births are twins. Such a slow reproductive rate makes the giant panda population highly susceptible to outside pressures, of which there are many.

Habitat loss is the panda's greatest threat, then poaching. Because of their singular devotion to bamboo, pandas must live where the plant is abundant. Today, the only suitable habitat is limited to 20 isolated sections of mountain forest in south-western China, all of which have thankfully been protected by the Chinese government with help from conservationist organisations like the World Wildlife Fund.



A newborn panda is practically hairless

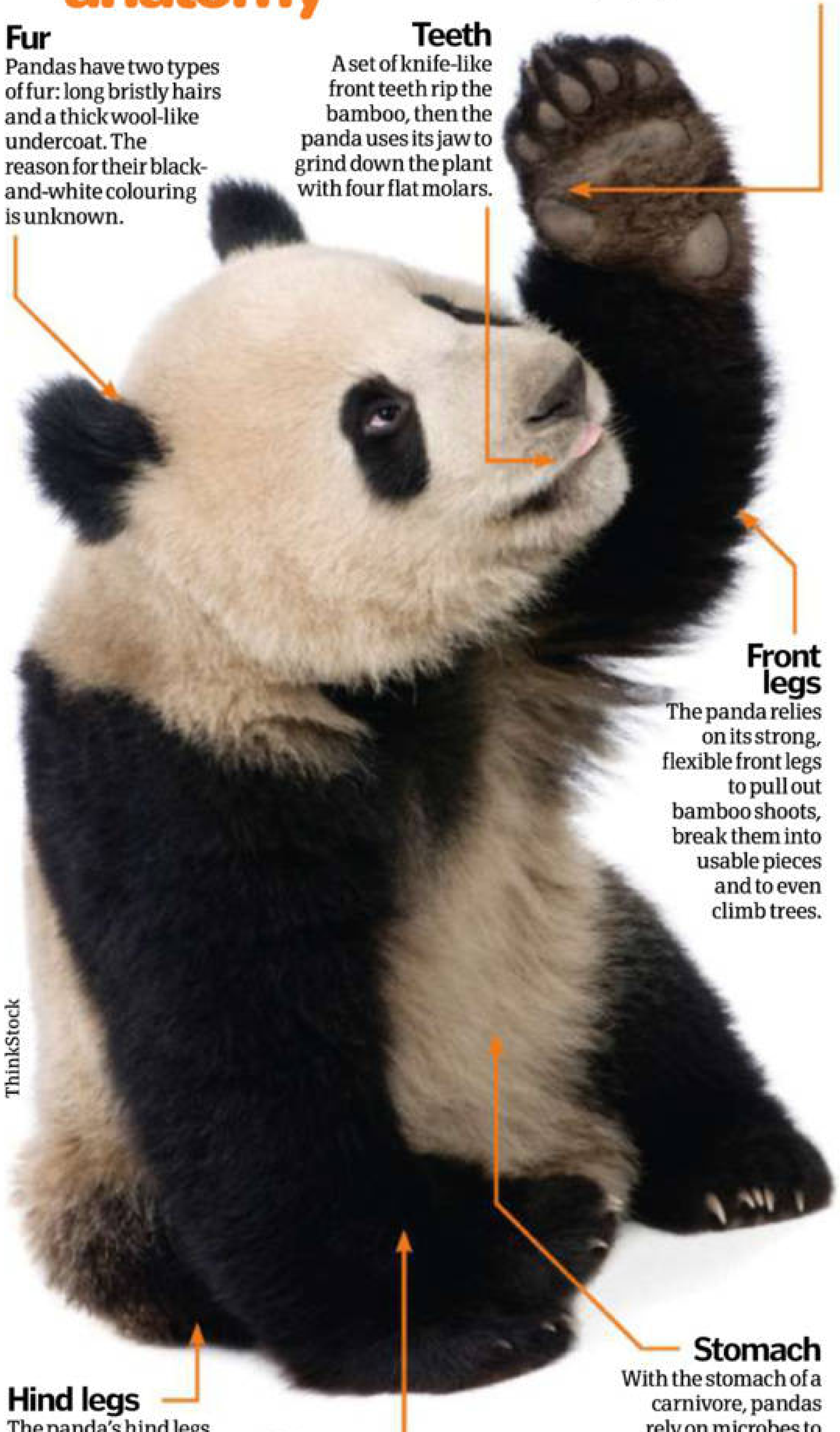
© The GIMP

Calories from food

The amount of energy an animal obtains from food is measured in calories. The following information reveals how many calories a panda must consume per day compared with other creatures.

ANIMAL	CALORIES CONSUMED PER DAY
Elephant	40,000
Giant panda	20,000
Adult humans	2,300-2,600
Mouse	20

Giant panda anatomy



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Paws
A pseudo-thumb, an elongated wrist bone covered with a thick pad of skin, is used for grasping bamboo stalks.

Fur
Pandas have two types of fur: long bristly hairs and a thick wool-like undercoat. The reason for their black-and-white colouring is unknown.

Teeth
A set of knife-like front teeth rip the bamboo, then the panda uses its jaw to grind down the plant with four flat molars.

Front legs
The panda relies on its strong, flexible front legs to pull out bamboo shoots, break them into usable pieces and to even climb trees.

Hind legs
The panda's hind legs are spread widely apart, helping it to sit comfortably for hours on end, but making it difficult to run.

Skin
The skin under a panda's black fur is grey and the skin under its white fur is pink. Newborn pandas are entirely pink and nearly hairless.

Stomach
With the stomach of a carnivore, pandas rely on microbes to help break down the abundant cellulose in bamboo. A thick layer of mucus protects against splinters.

The Statistics...

Giant panda

Species: Ailuropoda melanoleuca

Type: Mammal

Diet: Omnivore

Average life span in the wild: 20 years

Weight: Up to 136kg (300lbs)

Size: Up to two metres (6ft) head to tail and one metre (3ft) at the shoulders

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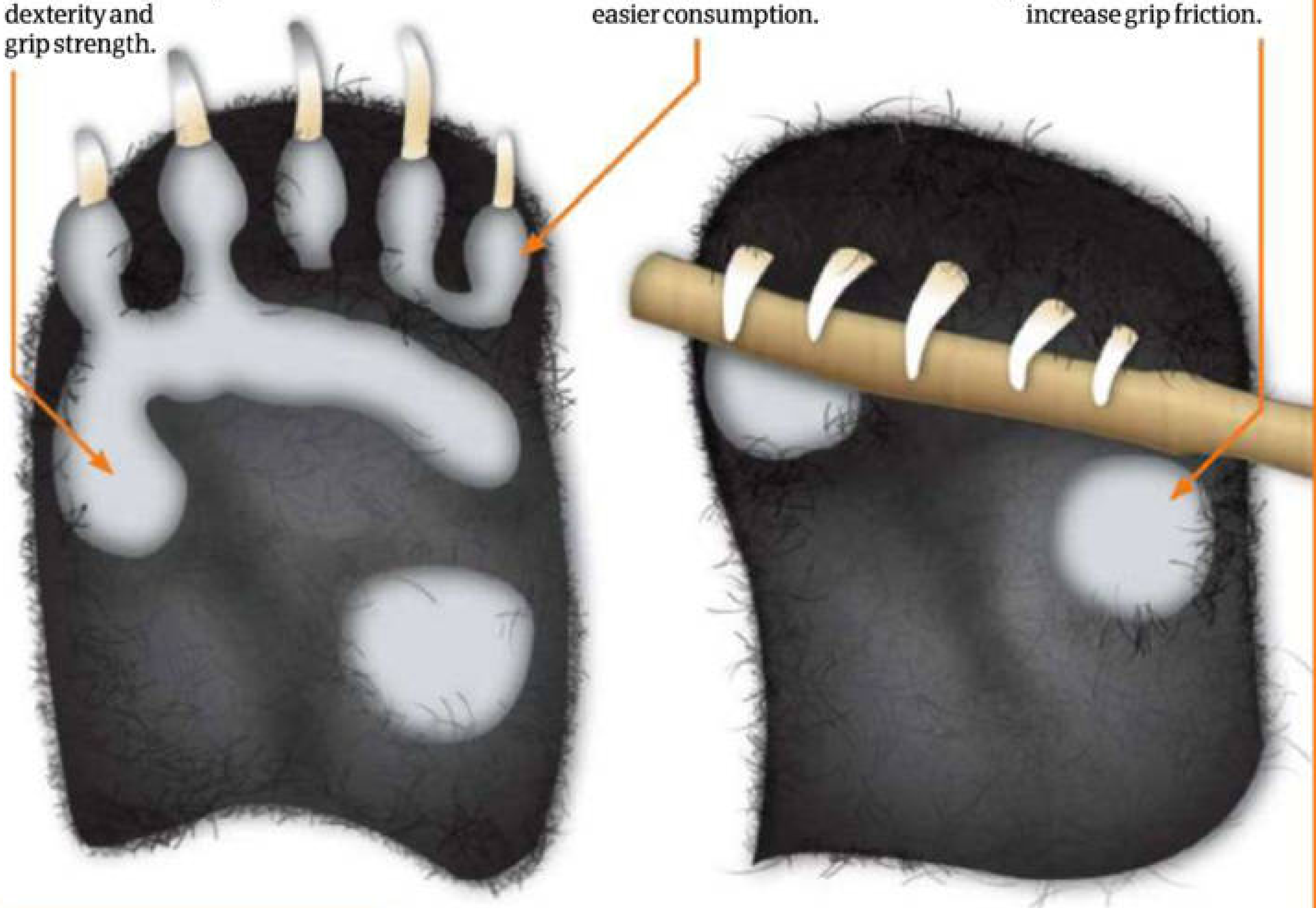
Without opposable thumbs, the panda had to adapt to grip bamboo

The grip of a panda...

Thumb
An evolved bone pseudo-thumb helps dexterity and grip strength.

Fingers
Five strong, bulbous fingers help strip bamboo for easier consumption.

Pads
Toughened skinned pads have developed to increase grip friction.

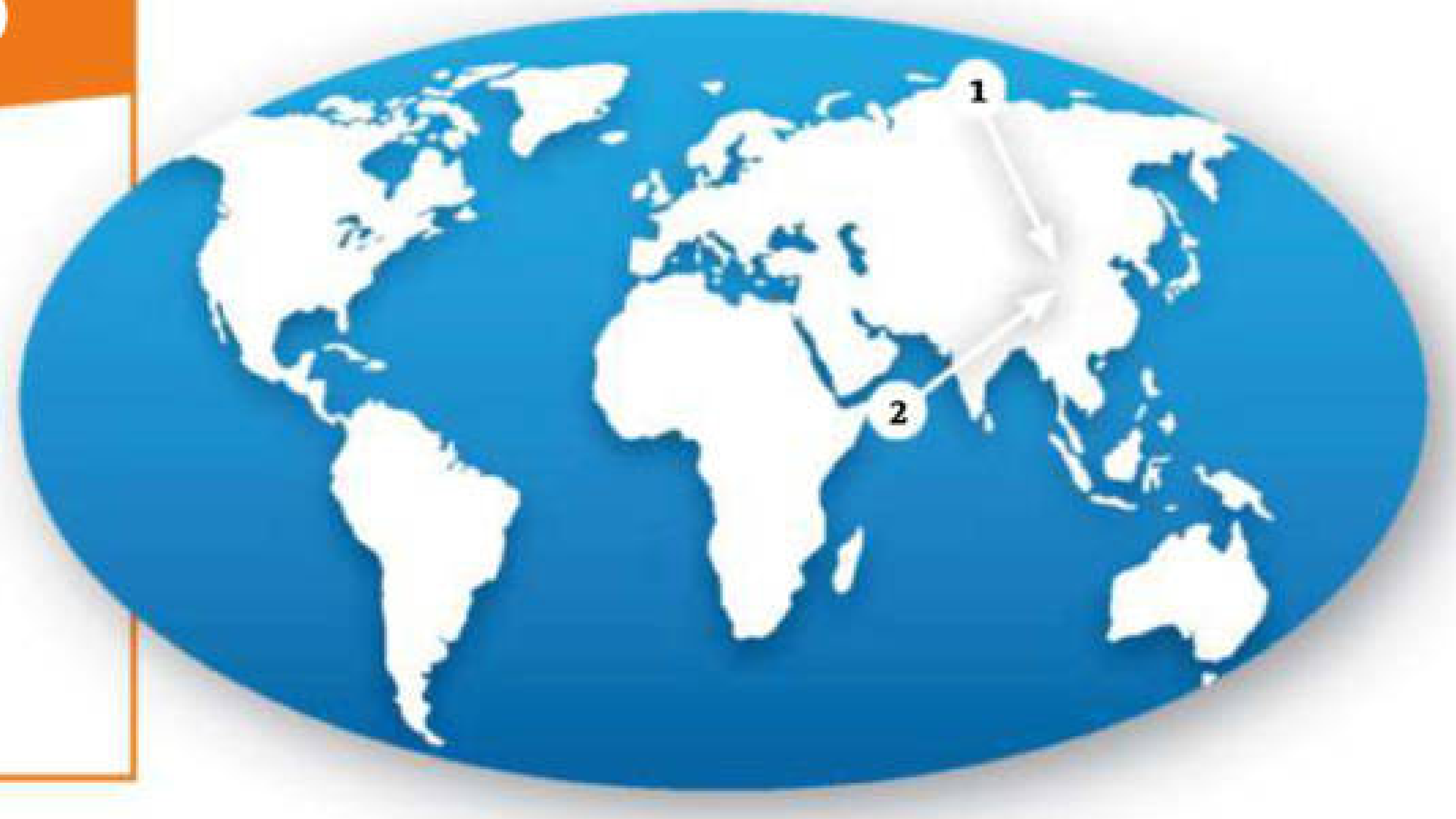


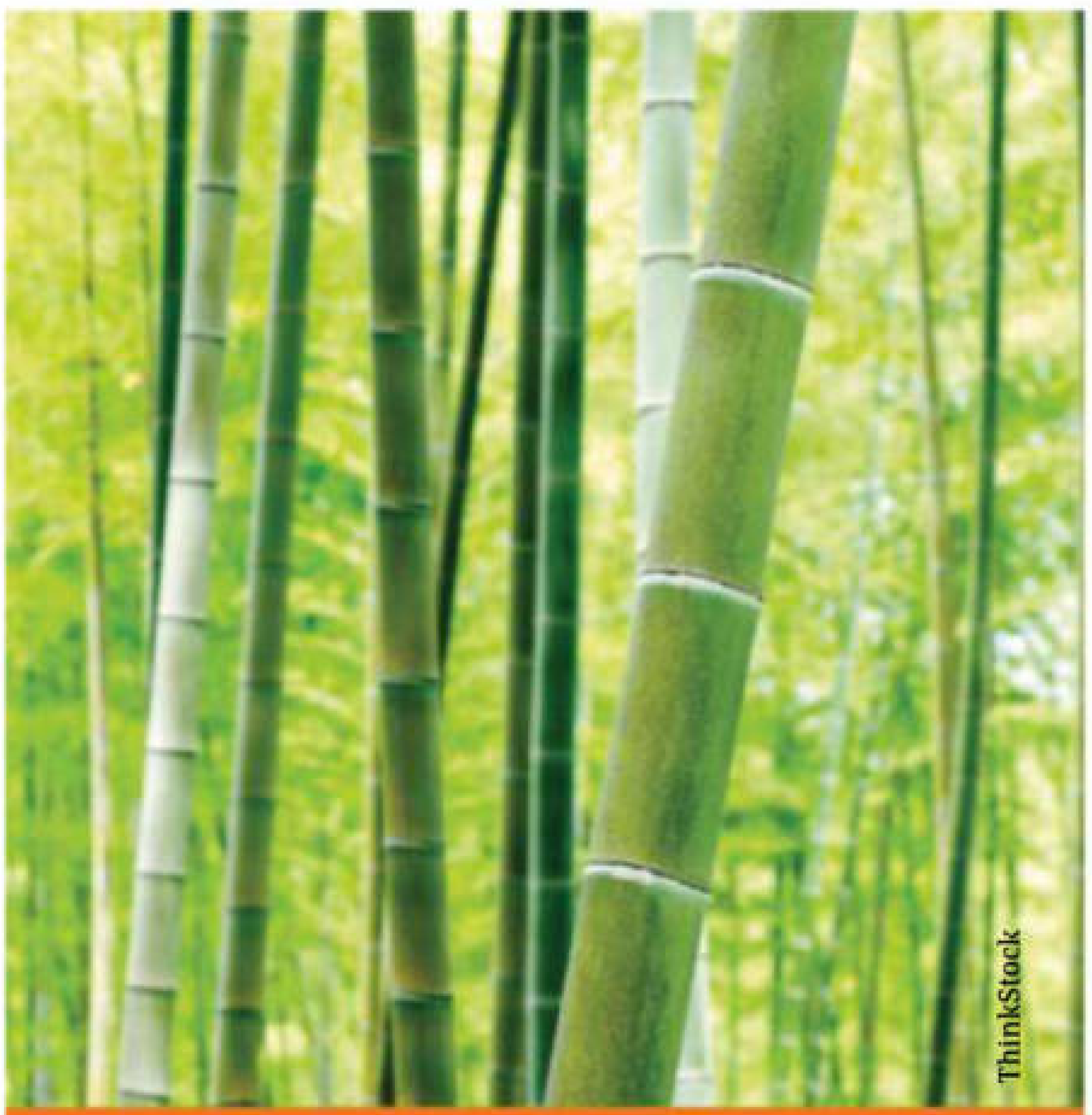
ON THE MAP

Where the wild pandas are...

1 Minshan mountains: 45% of the wild panda population live in these biodiverse Chinese mountain forests.

2 Qinling mountains: 200-300 pandas live on the cool, wet southern slopes of this Chinese range.





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Adapting to bamboo

It's the diet they were designed for, so why do pandas shun meat?

Although giant pandas are technically carnivores, they have adapted to eating a diet of 99 per cent bamboo, which they can barely digest. Pandas are genetically unable to turn cellulose into energy, so they must eat up to 38kg (84lbs) of the fibrous plant every day to get enough calories to survive. The task requires 12-16 hours of foraging and eating.

The panda's gut has developed a thick layer of mucus to protect against bamboo splinters. So, aside from the rare rodent or bird, why don't pandas eat meat? Clues in the recently sequenced panda genome point to a genetic mutation that may render them unable to taste flesh. Fossil studies show that the giant panda's ancestors swapped meat for bamboo somewhere between two and seven million years ago – perhaps due to a major environmental event wiping out their prey. Being forced to change their diet may have caused the gene responsible for tasting savoury to become obsolete, and without it they might not have wanted to eat meat even when it became plentiful once again.

A 'carnivorous' panda will opt for bamboo over meat, every time

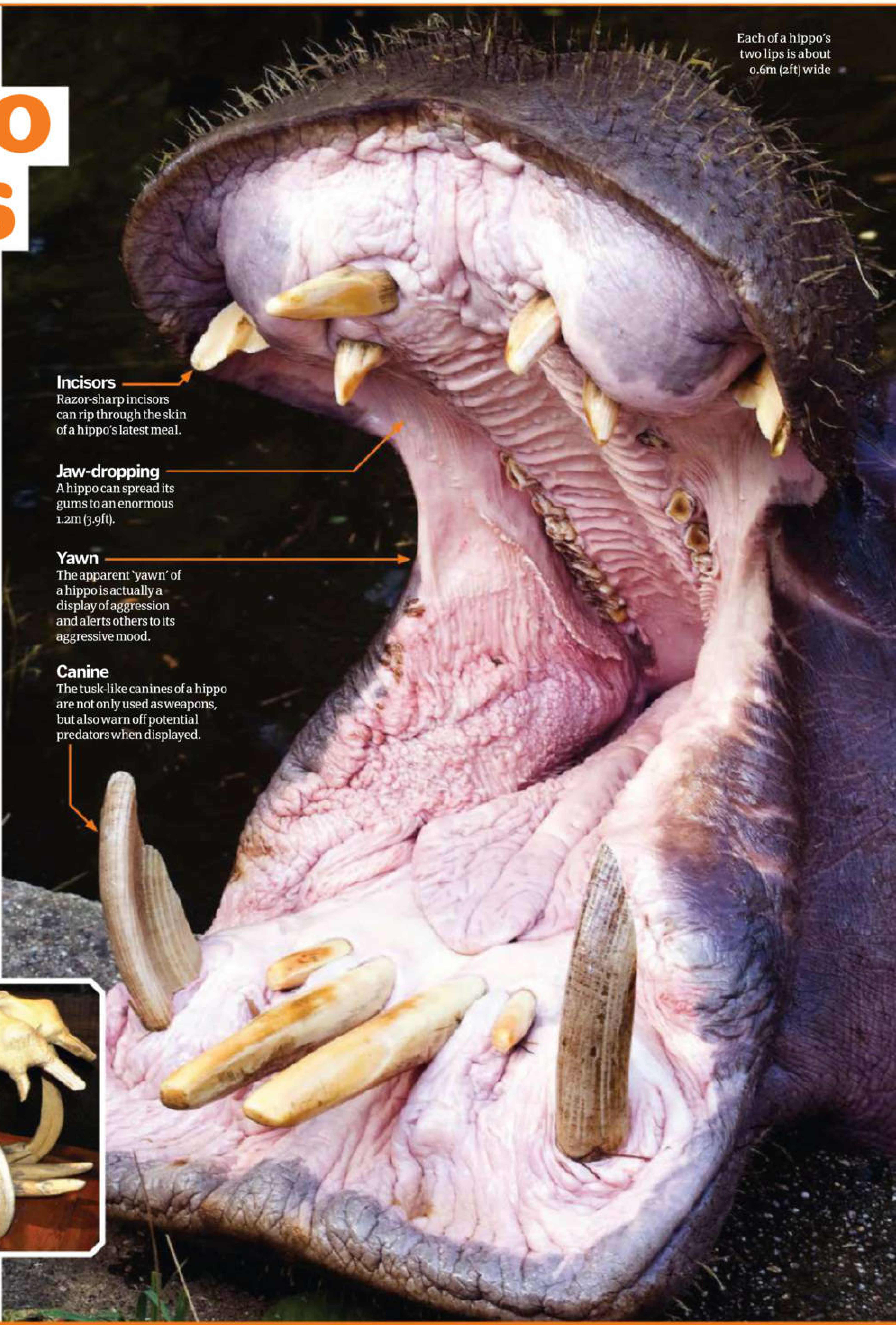
ThinkStock

Hippo jaws

How do these creatures open their mouths so wide?

A hippo may open its mouth wide as a sign of aggression, in a way similar to other animals such as lions and baboons. Opening their jaws shows others their fearsome set of weaponry: their teeth.

Although hippos eat vegetation, they do not use their teeth to do so. Their giant canines and incisors are used only for killing. Instead, they use their huge lips to rip grass from the ground for consumption. A hippo is able to spread its lips through a jaw-dropping 150 degrees and up to 1.2m (3.9ft) in width. The strength of a hippo's jaw muscles – a bite force of 1,800lb – is such that it can use its fearsome teeth to bite a crocodile, human, or even a small boat in half.



Each of a hippo's two lips is about 0.6m (2ft) wide

Incisors
Razor-sharp incisors can rip through the skin of a hippo's latest meal.

Jaw-dropping
A hippo can spread its gums to an enormous 1.2m (3.9ft).

Yawn
The apparent 'yawn' of a hippo is actually a display of aggression and alerts others to its aggressive mood.

Canine
The tusk-like canines of a hippo are not only used as weapons, but also warn off potential predators when displayed.

The skull of a hippopotamus contains tusk-like canines as long as your arm

© Raul654

A lie-in that we could only dream of…

Images © DK Images

Hibernation explained

Why can mammals go to sleep for months on end?

While birds and winged creatures can fly to warmer climes to escape cold and fruitless winters, many mammals enter a deep sleep to survive. This state is called hibernation and, depending on the animal, it can last between a few days, weeks, or even months.

In preparation for true hibernation, the animal must make a cosy burrow in which to sleep, and eat lots of food to store up as fat. Some animals can survive the whole winter on little or no food as the animal's heart rate and body temperature decrease, which means they use very little energy during hibernation.

Hibernating mammals also have two types of fat: regular white fat, which is used for storing energy and insulating the body, and a special brown fat that isn't burned for energy. This brown fat is most important to hibernation because it forms around the organs that need it most – the brain, heart and lungs – and generates heat to keep the animal alive.

DID YOU KNOW? Some desert-dwelling animals also enter a state of hibernation in order to survive droughts or hot weather. This is called aestivation.

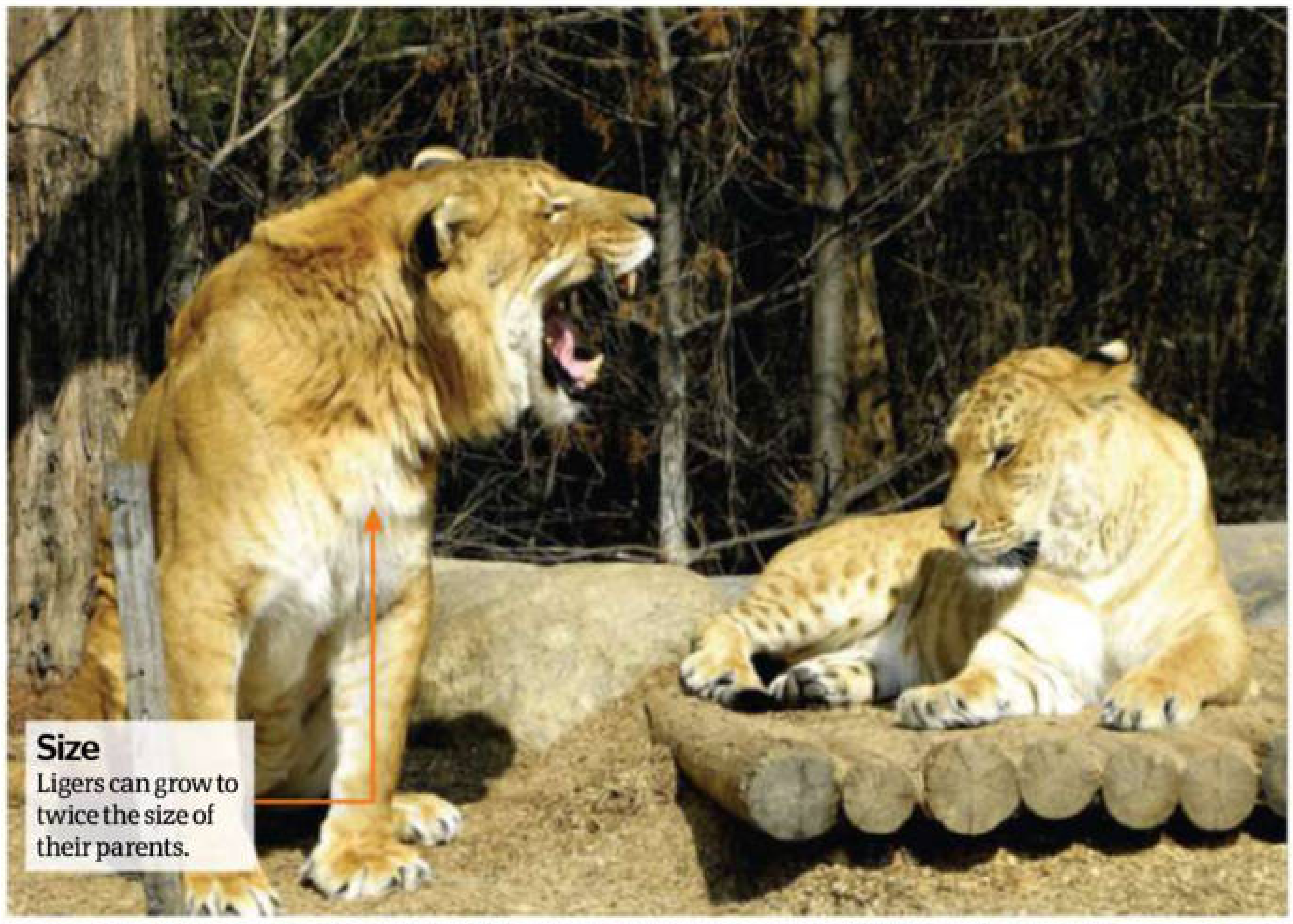
Ligers and tigons

When lions and tigers mate, new species are born

Ligers and tigons are two resultant species that emanate when lions and tigers cross breed. If a male lion mates with a tigress then a liger is born, if a male tiger mates with a lioness then a tigon is born. Both hybrid species are extinct in the wild as their respective habitats lead to minimal interaction, however many examples of both species can be found in captivity across the world in zoos and wildlife parks.

Ligers are now the more prevalent of the two species due to the greater probability of them living past birth, although during the early twentieth century this was not the case. The liger, as with the tigon, shares characteristics from both parent species – ligers enjoy swimming for example, a trait which is associated with tigers, however they also have spots, a characteristic gene of the lion – and tend to be bigger due to imprinted genes. Indeed, the current largest liger in the world weighs over 400 kilograms and is twice the size of its parents. Interestingly, though, tigons tend to suffer from dwarfism rather than gigantism as they always inherit the growth-inhibitory genes from the lioness mother, often weighing only around 200 kilograms.

Unfortunately, due to the hybrid man-made nature of ligers and tigons, growth disorders and degenerative diseases are common, as well as shortened life spans.


Size
Ligers can grow to twice the size of their parents.

A male liger in Novosibirsk Zoo, Russia

© Hardy

How flying squirrels glide

Is it a bird? Is it a plane? No, it's a squirrel!

Many arboreal (tree-dwelling) animals have developed wing-like extensions called patagia, which are elastic membranes stretched between their limbs or toes. These flaps of skin are ideal for helping them to glide through the air either to evade predators or to catch their own prey.

The southern flying squirrel is a nocturnal rodent capable of taking to the air and gliding from tree to tree in a single leap. The length of a single flight depends on the height at which the squirrel launches, but some can reach distances of up to 50 metres (165 feet). This form of gliding is known as volplaning.

Flying squirrels are found in North America and northern Europe, living in nests or natural cavities high in the trees. When down on the ground, however, they're a vulnerable target.

Flying squirrels are omnivorous and feast on a wide range of different food from nuts, fruit and fungi to many insects, bird eggs and even carrion from time to time.

The statistics…

Southern flying squirrel

Binomial name: Glaucomys volans

Type: Mammal

Diet: Omnivore

Average life span in the wild: 5 years

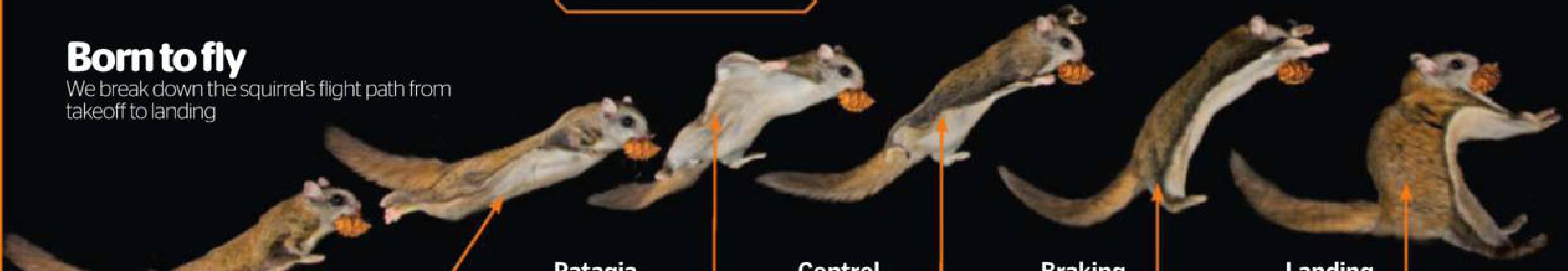
Weight: 15g-2kg (0.5oz-4lb)

Size: 10-90cm (4-35in)

Length of glide: 50m (165ft)

Born to fly

We break down the squirrel's flight path from takeoff to landing



Launch
The flying squirrel leaps out from a tree with its body tilted up and its arms and legs outstretched.

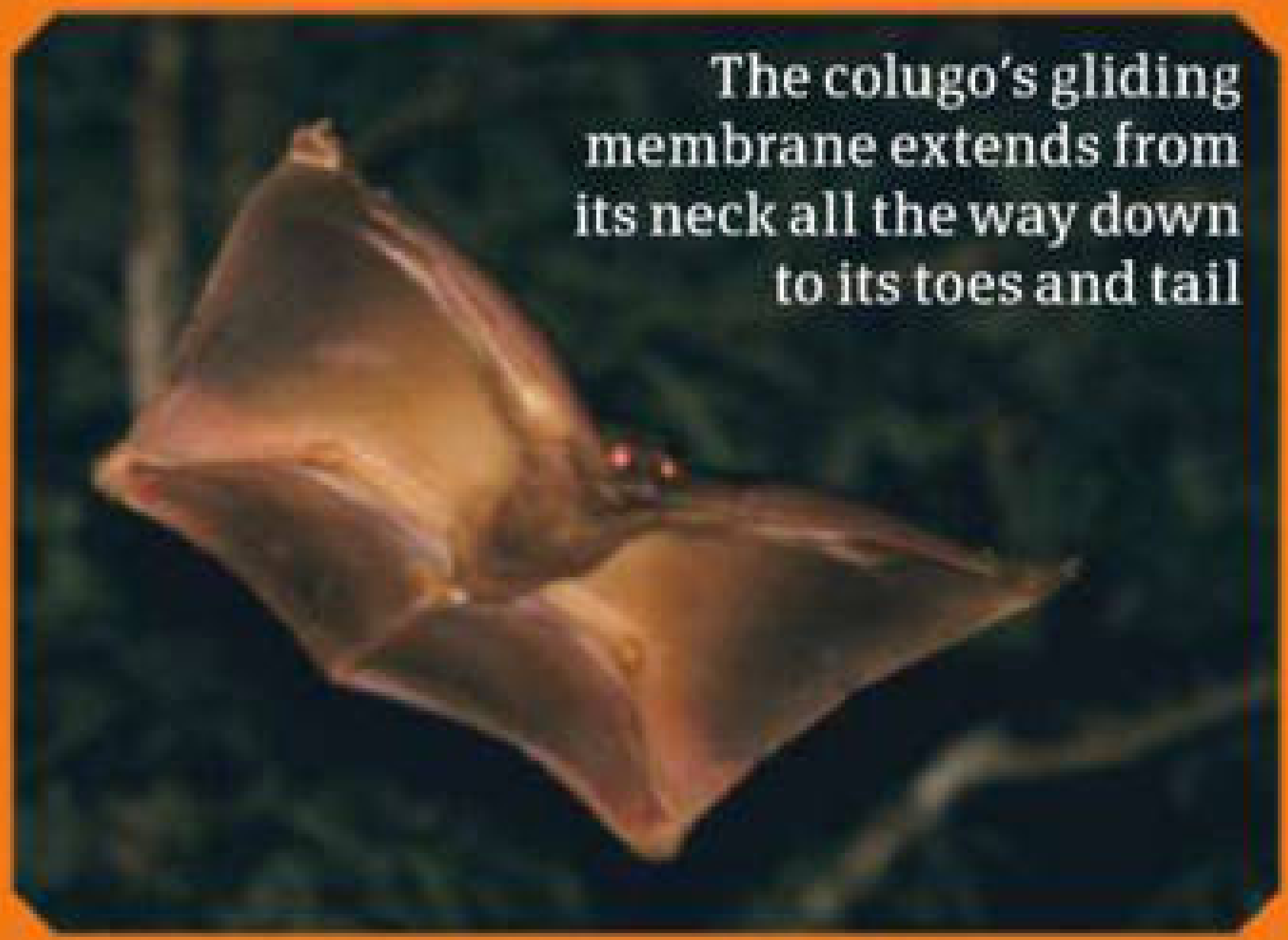
Stretch
After pushing off, the squirrel gains height and momentum. It then stretches its arms and legs out in front to help propel it forwards while it falls back down.

Patagia
Once the rodent gains altitude, it spreads its limbs to reveal a gliding membrane (the patagium) connected to the wrist and ankle on either side. These flaps fill with air, like a parachute, to create drag.

Control
The flying squirrel can dictate the direction in which it flies by steering with its legs, which it does by flattening its tail and stiffening the patagia, the two of which also act like an airfoil to generate lift.

Braking
During the descent, the creature flexes its entire body and tail upwards. Doing this enables the squirrel to change its angle of attack at the last moment by slowing its speed through the air, adjusting to the target.

Landing
Finally, as it comes in to land – typically on another tree trunk – the squirrel moves its body into a vertical position by swinging its hind legs down and forward ready to grasp tightly on to the new tree.



The colugo's gliding membrane extends from its neck all the way down to its toes and tail

Which other animals can glide?

Colugo
Though often called the flying lemur, it's actually a species of its own. About the size of a squirrel, but with a bat-like look, the colugo has the largest patagia of all gliders.
Length of glide:
Up to 70m (230ft)

Paradise tree snake
This reptile can launch itself into the air from a height and flatten its body into a ribbon shape with a concave underside that acts like an airfoil. It still moves in the air in an 'S' shape.
Length of glide:
Up to 100m (330ft)

Flying frog
This arboreal species has giant webbed feet that act like four airfoils. Flying frogs can be very nimble in flight, capable of banking from side to side like an aeroplane.
Length of glide:
Up to 15m (50ft)

Draco lizard
One of the greatest gliders. Sometimes called flying dragons due to their airborne antics, the Draco lizard has a large semicircular wing-like flap attached to either side of its ribs.
Length of glide:
Up to 9m (30ft)

© Alamy; Getty

Why camels have the hump

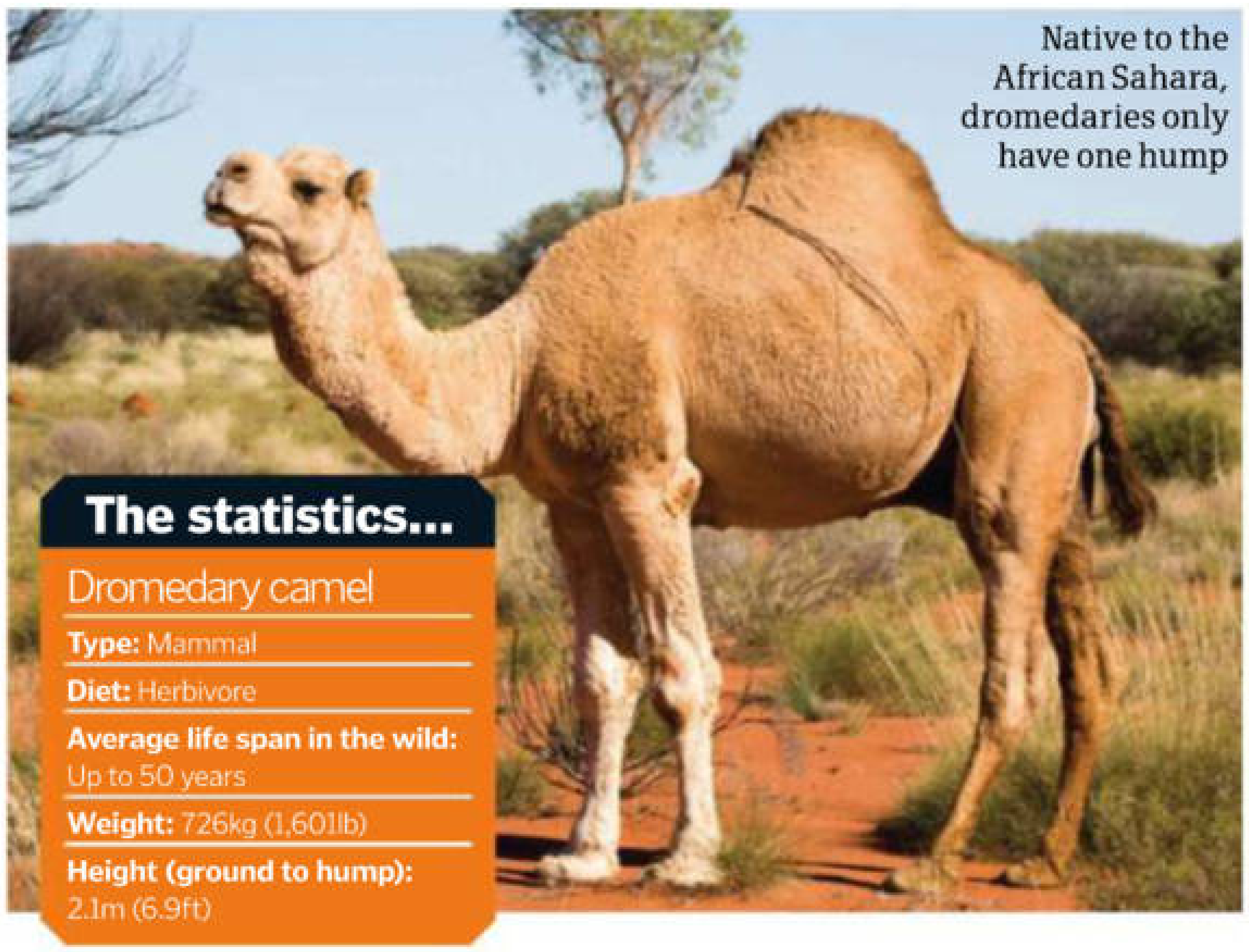
How do these 'ships of the desert' adapt to life in extreme climates?

Camels are experts at living in places where food and water are relatively scarce. The reason that they can survive in such arid terrain is their amazing ability to conserve the water they do take on so that they can draw upon it later when needed. When a dehydrated camel finds a water source, it can lap up as much as 120 litres (32 gallons) in 15 minutes. To conserve the lifesaving H2O, camels can regulate their body temperature so that they hardly sweat at all. Their kidneys can concentrate the urine to further reduce water loss.

Not only this but these creatures also store a lot of water in their blood; the erythrocytes (red blood cells) can swell to over twice their normal size without bursting. Thanks to this tailored physiology, camels can go for weeks with little to no food or water without suffering adverse effects.

However, when sustenance is in seriously short supply, they make use of a secret energy stash on their backs. The camel's hump does not store water; it functions as a reserve of adipose tissue (fat cells) that can be metabolised in order to provide emergency energy to the camel. As the fat is depleted, the hump will begin to wilt and flop to one side.

These fatty humps are great for keeping cool too because fat conducts the Sun's heat relatively slowly, and the camel's woolly covering provides it with some extra insulation.



Native to the African Sahara, dromedaries only have one hump

The statistics...

Dromedary camel

Type: Mammal

Diet: Herbivore

Average life span in the wild: Up to 50 years

Weight: 726kg (1,601lb)

Height (ground to hump): 2.1m (6.9ft)

Why are kangaroos expert jumpers?

Discover why this antipodean animal is a natural-born long jumper

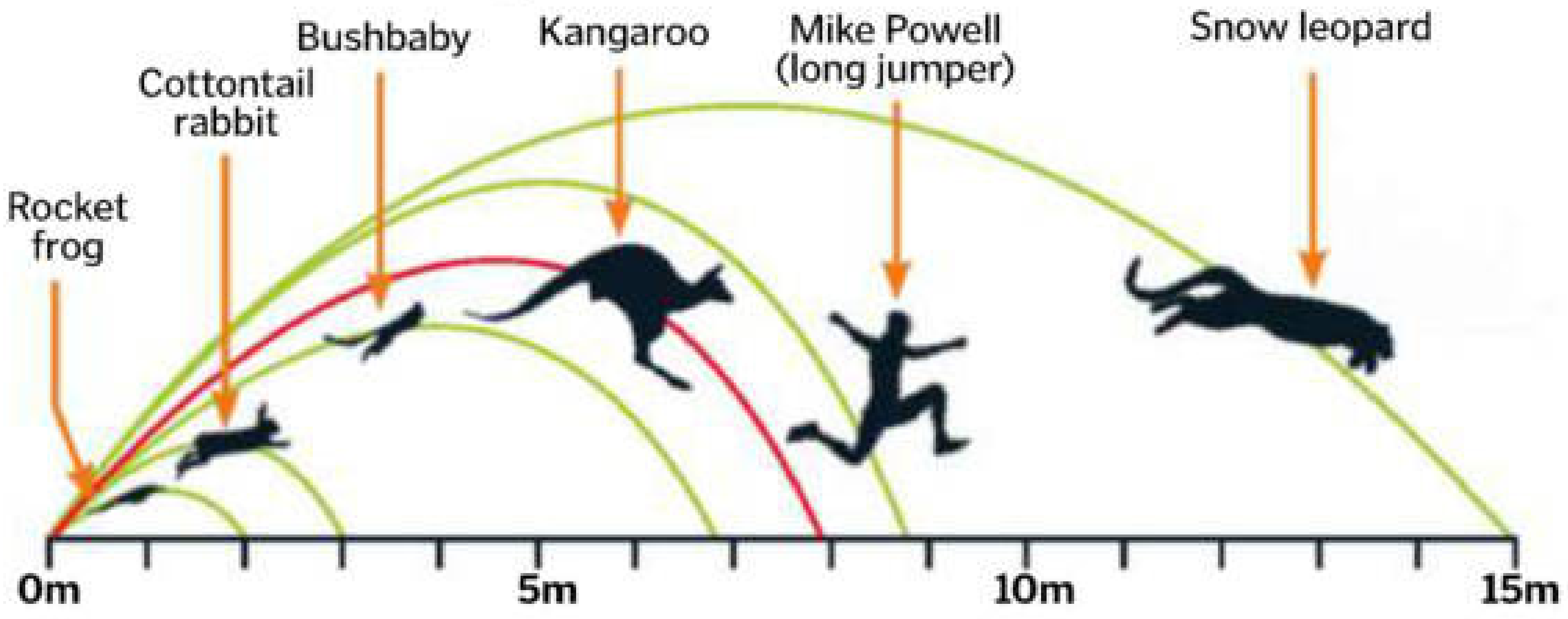
In a huge country such as Australia, the ability to cross vast distances in search of food and water is key to survival. And one such animal that can traverse barren lands at high speed for hours is the kangaroo.

Capable of an eight-metre (25-foot) single bound across level ground, the red kangaroo is one of the world's greatest long jumpers. Thanks to large feet and strong legs, it can also travel at over 50 kilometres (30 miles) per hour. While a kangaroo's hind legs are big and powerful, however, they can't work independently of each other and so kangaroos have to hop on two feet unless they want to try crawling.

The hind leg tendons are strong and elastic and, with every hop, elastic energy is recaptured in the tendons ready for the next jump.

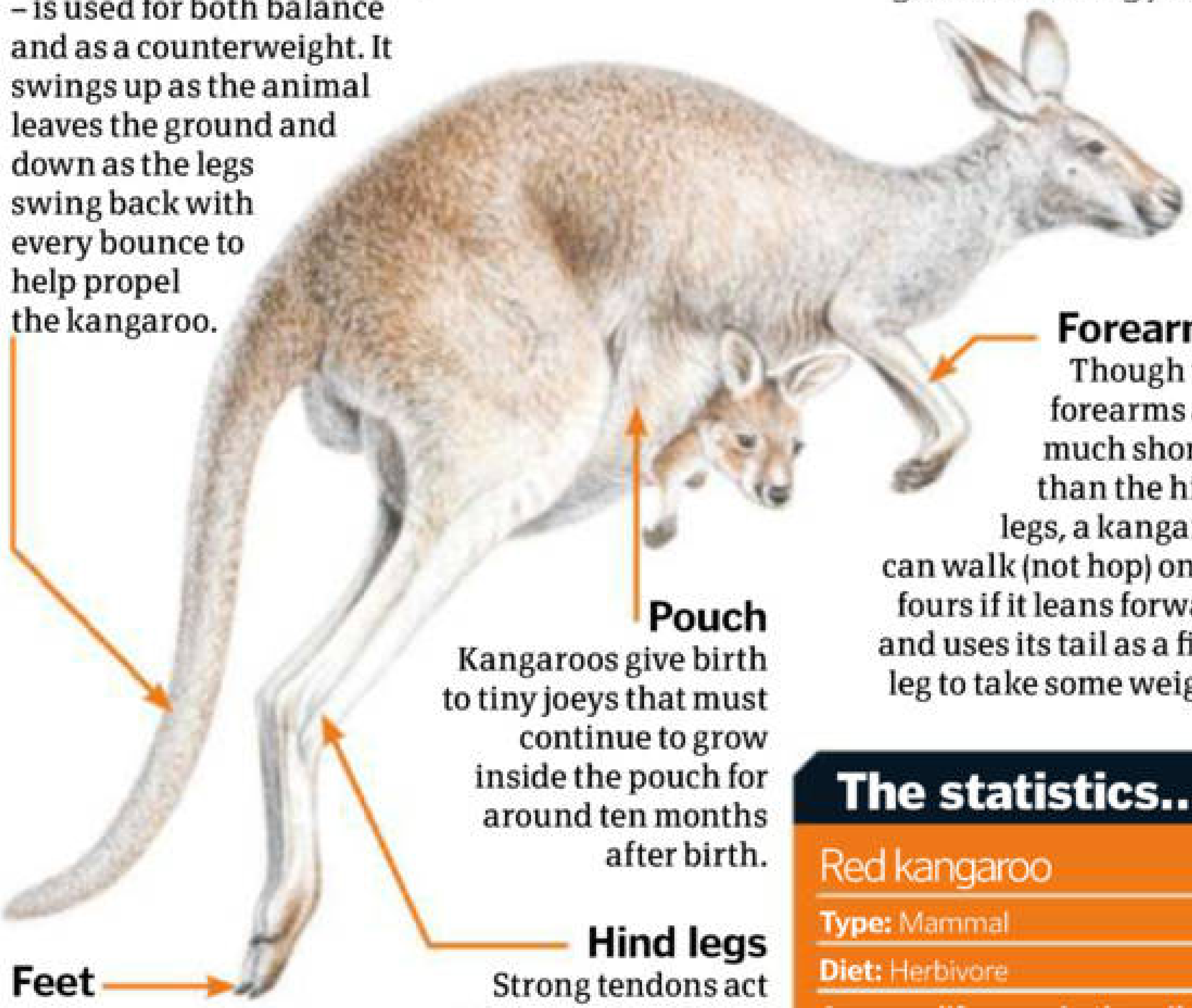
To help the bounce, kangaroos use their tails as a counterbalance. It propels the animal in a similar way to using your legs on a swing to gain momentum. When the kangaroo's back legs are fully outstretched behind it the tail is in the downward position, and when the legs are pushing forwards the tail is high in the air.

Who can leap the farthest?



Built to bounce

Why is this Australian marsupial so good at the long jump?



Tail
The long tail – up to 1m (3.3ft) – is used for both balance and as a counterweight. It swings up as the animal leaves the ground and down as the legs swing back with every bounce to help propel the kangaroo.

Forearms
Though the forearms are much shorter than the hind legs, a kangaroo can walk (not hop) on all fours if it leans forward and uses its tail as a fifth leg to take some weight.

Pouch
Kangaroos give birth to tiny joeys that must continue to grow inside the pouch for around ten months after birth.

Feet
A kangaroo's big toes are in the centre of the other toes (not to one side like ours) in line with their leg bones, enabling them to push off with force.

Hind legs
Strong tendons act like tight springs that store and release energy. On landing, the spring compresses to store energy ready for the next hop.

The statistics...

Red kangaroo

Type: Mammal

Diet: Herbivore

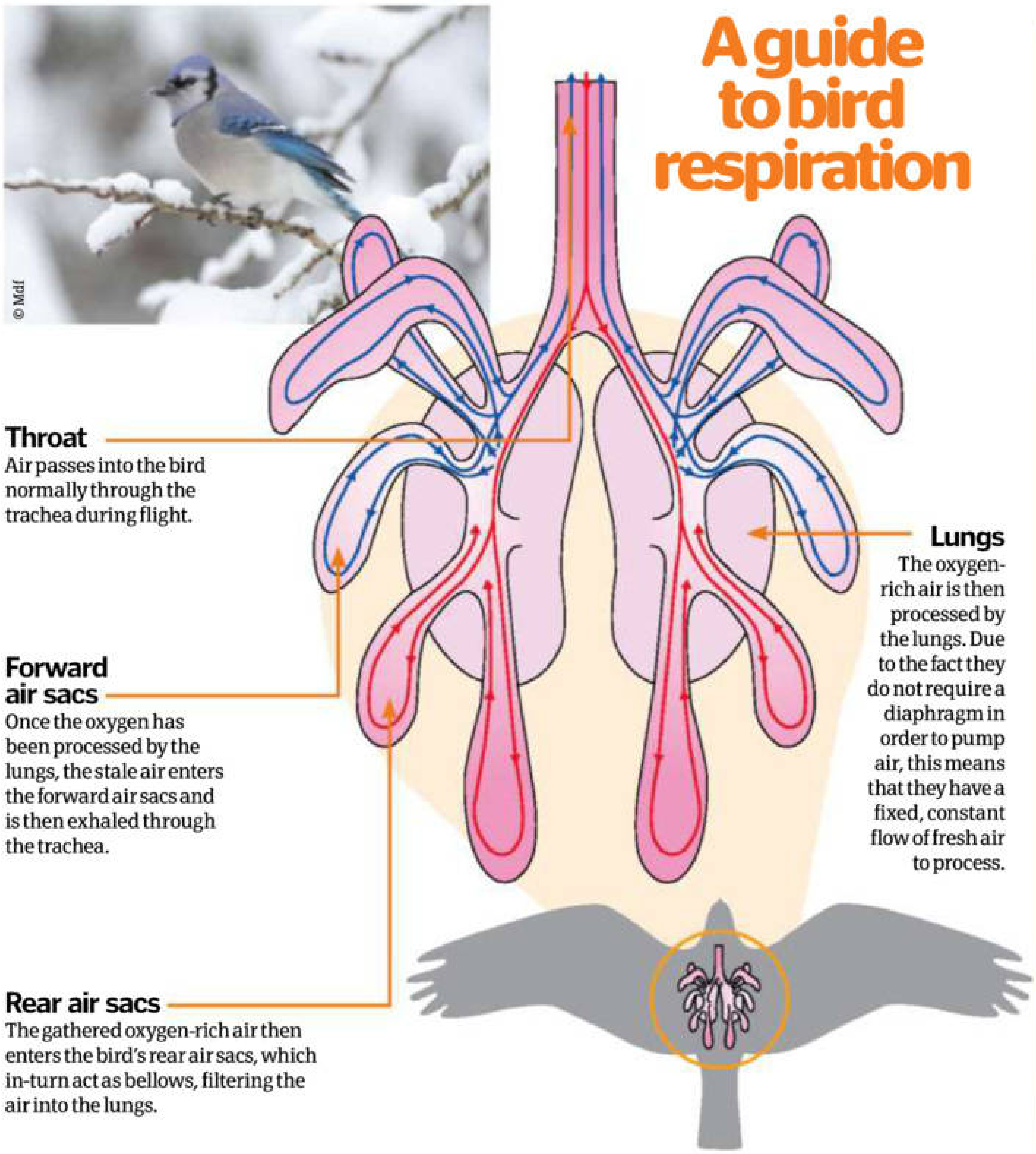
Average life span in the wild: 20 years

Weight: 90kg (200lb)

Size: 1-1.6m (3.3-5.3ft)

Speed: 56km/h (35mph)

© Thinkstock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A guide to bird respiration

Throat
Air passes into the bird normally through the trachea during flight.

Lungs
The oxygen-rich air is then processed by the lungs. Due to the fact they do not require a diaphragm in order to pump air, this means that they have a fixed, constant flow of fresh air to process.

Forward air sacs
Once the oxygen has been processed by the lungs, the stale air enters the forward air sacs and is then exhaled through the trachea.

Rear air sacs
The gathered oxygen-rich air then enters the bird's rear air sacs, which in-turn act as bellows, filtering the air into the lungs.

How do birds breathe?

Forced to evolve due to an exceedingly high metabolic rate and oxygen demand, birds sport an efficient and refined respiratory system

Birds breathe by partnering a pair of lungs without a diaphragm with a system of internal air sacs that act as bellows. The reason for this is due to the bird's high metabolic rate and oxygen demand when flying, constantly needing a stream of oxygen-rich air to process in order to remain active.

This would not be possible with the bi-directional lungs of mammals because oxygen-rich air is mixed with oxygen-deficient stale air during the breathing process, reducing the amount of oxygen that can be processed in the lungs at any one time.

However, with the unidirectional flow that is made possible by separating the pump part of the breathing process (the sacs) with the absorption part (the lungs), a constant oxygen-rich stream can be maintained. Avian lungs do not process oxygen with alveoli as mammal lungs do, but absorb it through honeycombed-structured passages referred to as parabronchi into air vesicles, which themselves contain oxygen/carbon dioxide trading capillaries.

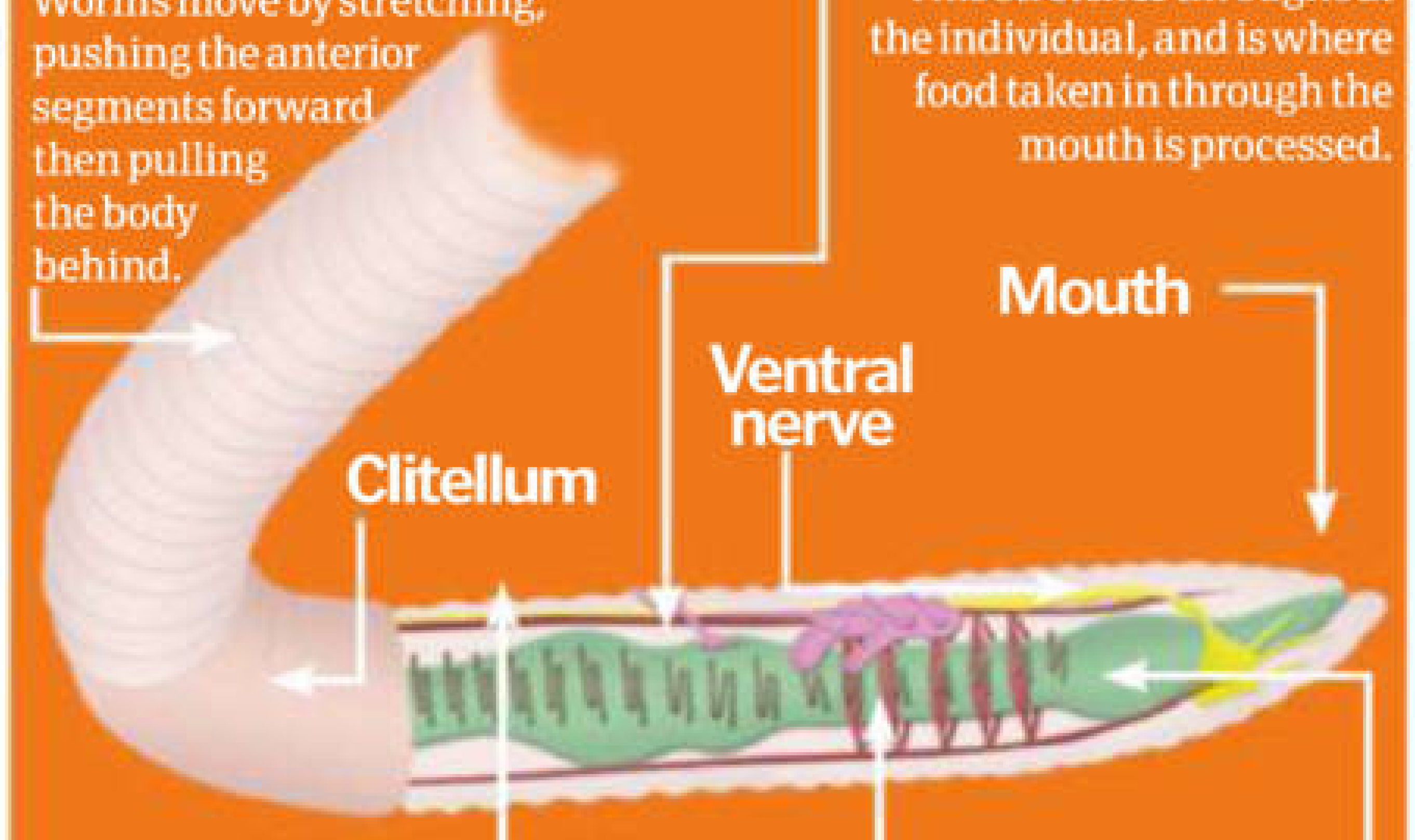
Earthworms

Worms are well known to us, often spotted in back gardens across the country – but more importantly, can they actually survive if they are cut in two?

Earthworms need moisture to survive and consequently they are commonly found living underground in damp soil. They are cylindrical in shape, and their body structure is surprisingly simple with a muscular outside body that lines their digestive tract and circulatory system.

This circulatory system is very simple, with only two blood vessels (the dorsal and the ventral) which run between the anterior and posterior of the creature, with blood being pumped by aoertic arches in the case of the ventral vessel, or moved back to the anterior by the dorsal vessel contracting. However, although simple, earthworms do display distinct segments, which are more specialised towards the anterior (head). Consequently, segments situated further back in the body can be regenerated in many cases, but it is dependant on the type of species and the actual extent of damage.

Earthworms are also hermaphrodites, holding both male and female sexual organs, however they commonly mate and then store the other individual's sperm for reproduction.



Muscular body
Worms move by stretching, pushing the anterior segments forward then pulling the body behind.

Digestive tract
This stretches throughout the individual, and is where food taken in through the mouth is processed.

Dorsal vessel
This brings blood that has been pumped down the body back to the front to be oxygenated and then pumped back down the ventral vessel.

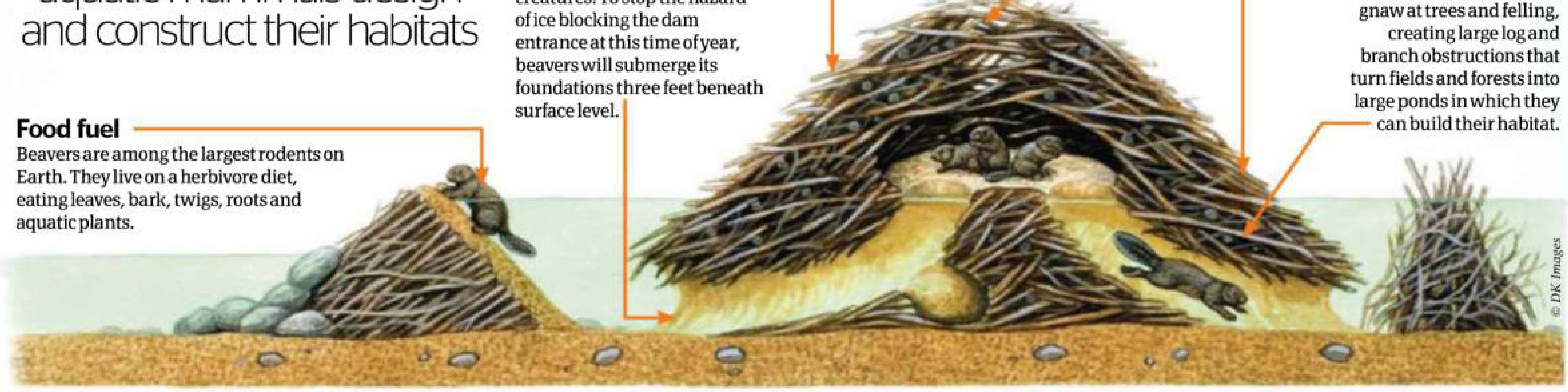
Ventral vessel
Blood gets pumped by the aoertic arches down the body to supply oxygen wherever it is needed.

Aoertic arches
These work like a human heart, pumping the blood around the worm's body. The number of these present varies between species.

Anatomy 101
Upon dissecting an earthworm it's easy to see the digestive tract wrapped in aortic arches, transporting blood down the body

Beaver dams

We explore how these aquatic mammals design and construct their habitats



Food fuel
Beavers are among the largest rodents on Earth. They live on a herbivore diet, eating leaves, bark, twigs, roots and aquatic plants.

Home sweet home
A beaver's lodge, often found in the middle of a pond, is accessible only by water. These dwellings are home to extended families.

Safe depths
Winter seasons are perilous for all aquatic creatures. To stop the hazard of ice blocking the dam entrance at this time of year, beavers will submerge its foundations three feet beneath surface level.

Standing tall
The average height of a beaver lodge reaches up to six feet tall, with an average depth of water behind the dam of four to six feet. This makes it a great place to look out for predators, and keeps it a safe distance from shore.

Made to last
The thickness of the dam can measure up to five feet or more. The length depends on the width of the habitable stream, averaging 15 feet. This makes for a very sturdy home in all weather conditions.

Rodent renovation
Renovation is the name of a beaver's game. Apart from building dams, they can gnaw at trees and felling, creating large log and branch obstructions that turn fields and forests into large ponds in which they can build their habitat.

© DK Images

Beavers are aquatic mammals with a keen affection for engineering, demonstrated in the construction of their artificial dam habitat. This ingenuity is one of nature's greatest wonders, and has been happening for well over 10 million years. Fundamentally, the building of a dam suits the natural instinct of this species. The beaver is an adapted swimmer but it is fairly immobile upon land. This weakness makes it susceptible to larger predators such as the bear.

Their strong aquatic skills make deep water habitats far more secure. Skilled teams of constructor beavers, usually working in pairs, can build a dam in a matter of days. The dam itself is constructed from an eclectic mix of natural materials, including rocks, wet grass, wood and mud to build the superstructure. A minimum level of three feet is required to keep the dam's underwater entrance from freezing over in winter. A beaver's dam will vary in construct and design, dependent on water speeds in the river. If the dam is straight, then the water current is slow. If it's curved, the water current is fast moving.

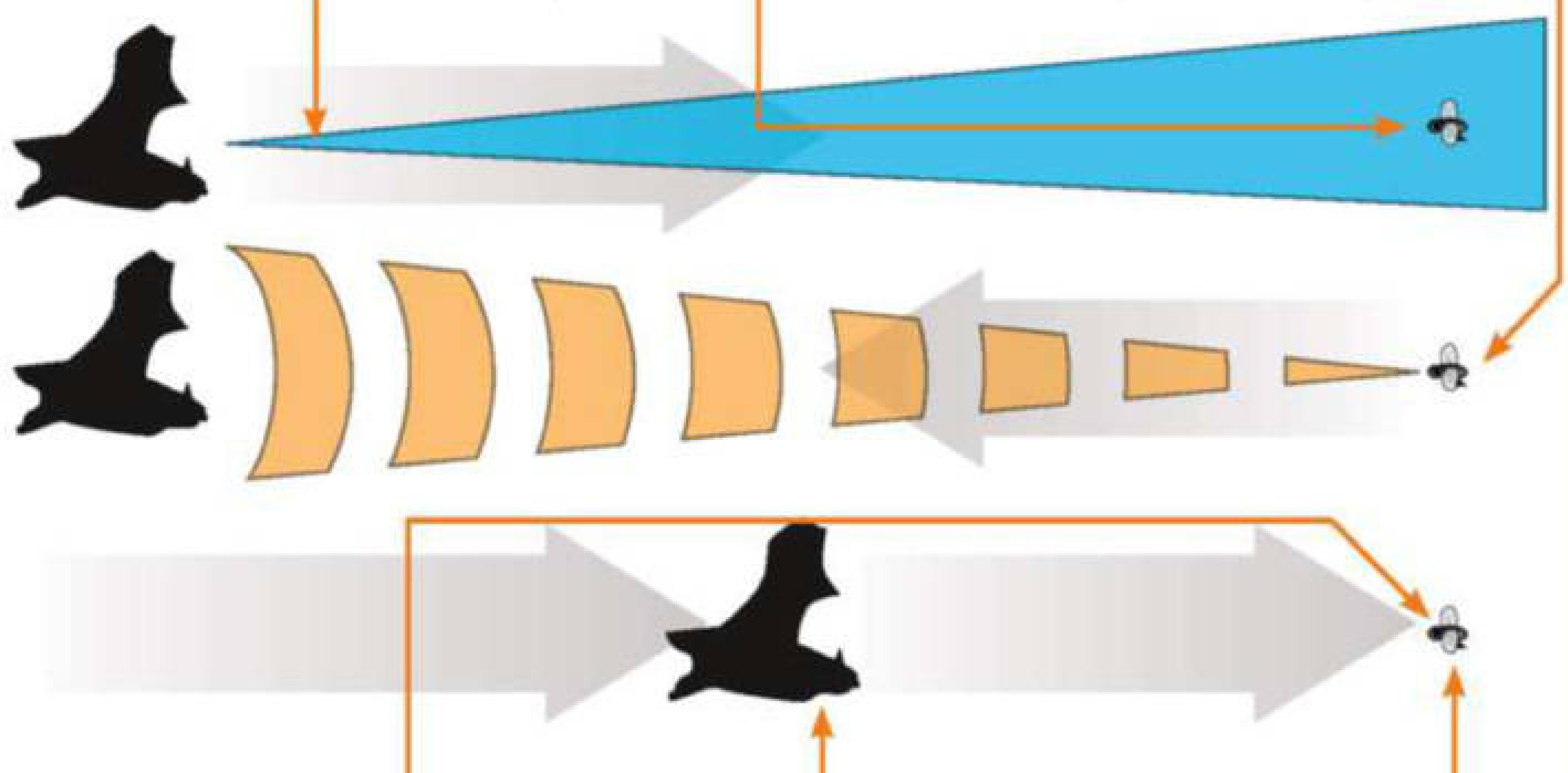
Bats' ultrasonic sonar system

We reveal how Chiroptera's supersonic hearing happens

Contrary to belief, bats (Chiroptera) do demonstrate an acute sense of vision, however this is accommodated during daylight conditions. When night falls, these small mammals are more inclined to use their heightened sense of hearing when hunting prey and manoeuvring around habitats, never being at a disadvantage. This is complemented by their incredible biological sonar navigation system.

But how does this work? Well, bats are inclined to emit ultrasonic sounds, with a frequency of between 50,000 and 200,000 vibrations per second, too high-pitched for human ears to comprehend.

These sound are emitted 20 to 30 times each second in all directions, with the bat listening between pulses, scanning for echoes with its head in perpetual motion. Bats separately perceive and process overlapping echo delays, arriving as little as two microseconds apart, that's an impressive two thousandths of a second. The bat's own nervous system supports this fined-tuned capability, allowing Chiroptera to identify echo-reflecting points on an object the width of a pen line on paper, or objects as close together as three-tenths of a millimetre.



Emitting sound
Bats emit ultrasonic sounds 20 to 30 times each second, listening between pulses for echoes.

Timing and direction
The bat then registers distance and location of prey through the timing and direction of the returning sound waves.

Translating echo
The time between sending out a cry and then receiving a response is translated by the bat into distance, between itself and whatever object is in the vicinity.

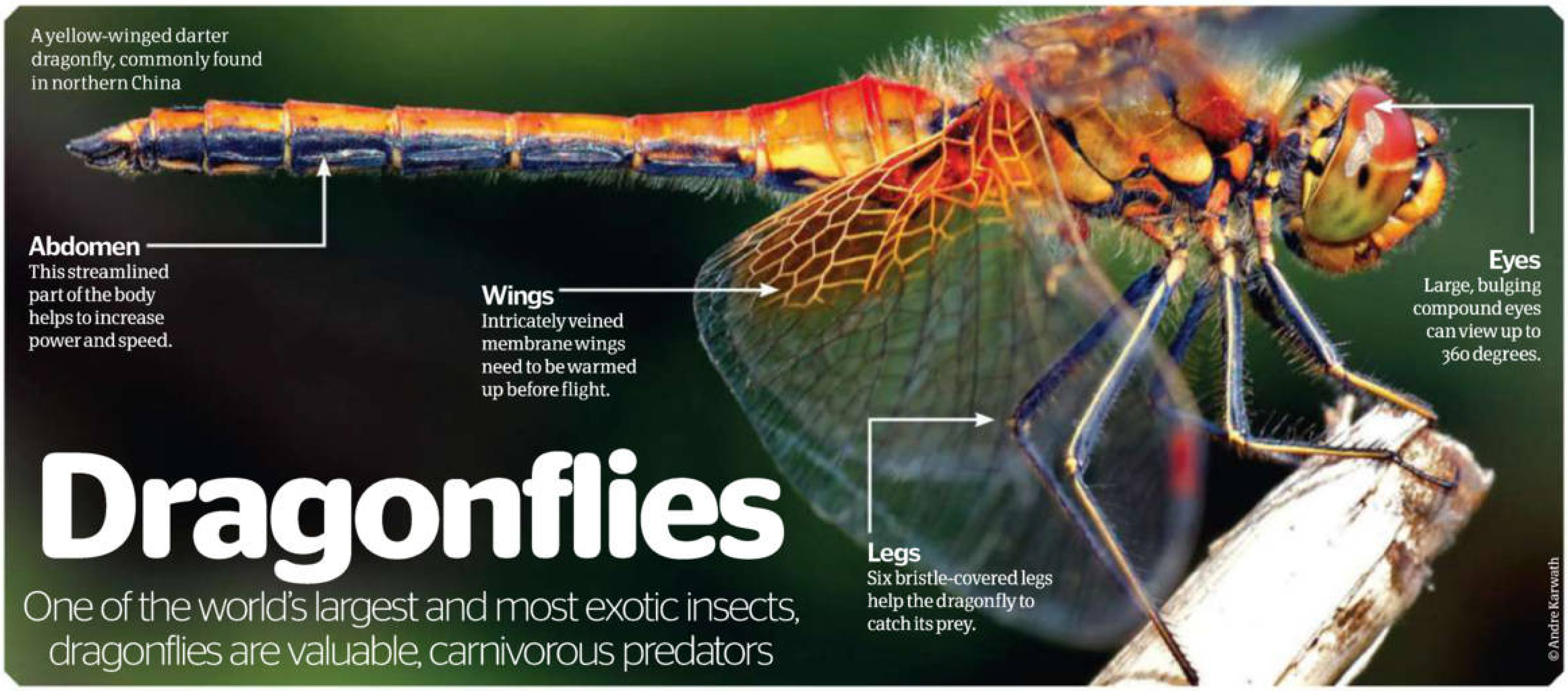
Moving prey
The bat realises moving prey through delayed sound and a slightly lower or higher pitch, due to the Doppler effect.

Sourcing insects
Echoes from prey such as mosquitoes, moths and butterflies reveal fluctuations, which are caused by the flutter of their wings, easily recognised by the bat.

Stationary prey
Stationary objects are instantly recognisable, as these yield an echo that is a replica of the pulse sent out by the bat.

Dragonflies

One of the world's largest and most exotic insects, dragonflies are valuable, carnivorous predators



A yellow-winged darter dragonfly, commonly found in northern China

Abdomen This streamlined part of the body helps to increase power and speed.

Wings Intricately veined membrane wings need to be warmed up before flight.

Eyes Large, bulging compound eyes can view up to 360 degrees.

Legs Six bristle-covered legs help the dragonfly to catch its prey.

© Andre Karwath

Similar to but typically much larger than damselflies, dragonflies are large, agile insects that undertake a valuable role in the Earth's ecosystems, eating mosquitoes and other smaller insects. Their powerful flight abilities stem from their streamlined abdomen and dual sets of intricately veined, membrane wings, which allow them to fly at speeds up to 60mph. Dragonfly wingspans range from one-inch up to six inches. Their agility also stems from large bulging compound eyes, which on some of the larger species grant them almost 360-degree vision.

Unfortunately, this high performance comes at a cost – dragonfly muscles need to be warm in order to function properly. Therefore, for dragonfly wings to function optimally, the insect has to engage in a series of stationary wing-whirring exercises and elongated periods of basking in the Sun to generate the requisite heat before taking off. However, when in flight, the large, warm and toned muscles deliver the dragonfly complete six-way propulsion, allowing it to move from a stationary/hovering position directly upwards, downwards, forwards, backwards and left to right.

Young dragonflies are called larvae and are aquatic rather than aerial predators. At this stage of their lifespan, they don't possess any wings but sport a formidable anatomical structure not present in adults called the 'mask'. The mask is a disproportionately large structure, to which a set of larger fangs is attached. When not in use, the mask is concealed under the larvae's thorax, extended to capture prey such as tadpoles and aquatic worms. Larvae transform into full-grown dragonflies through a series of moultings, the final one leaving a distinctive exuvia (cast skin) behind.

Metamorphosis

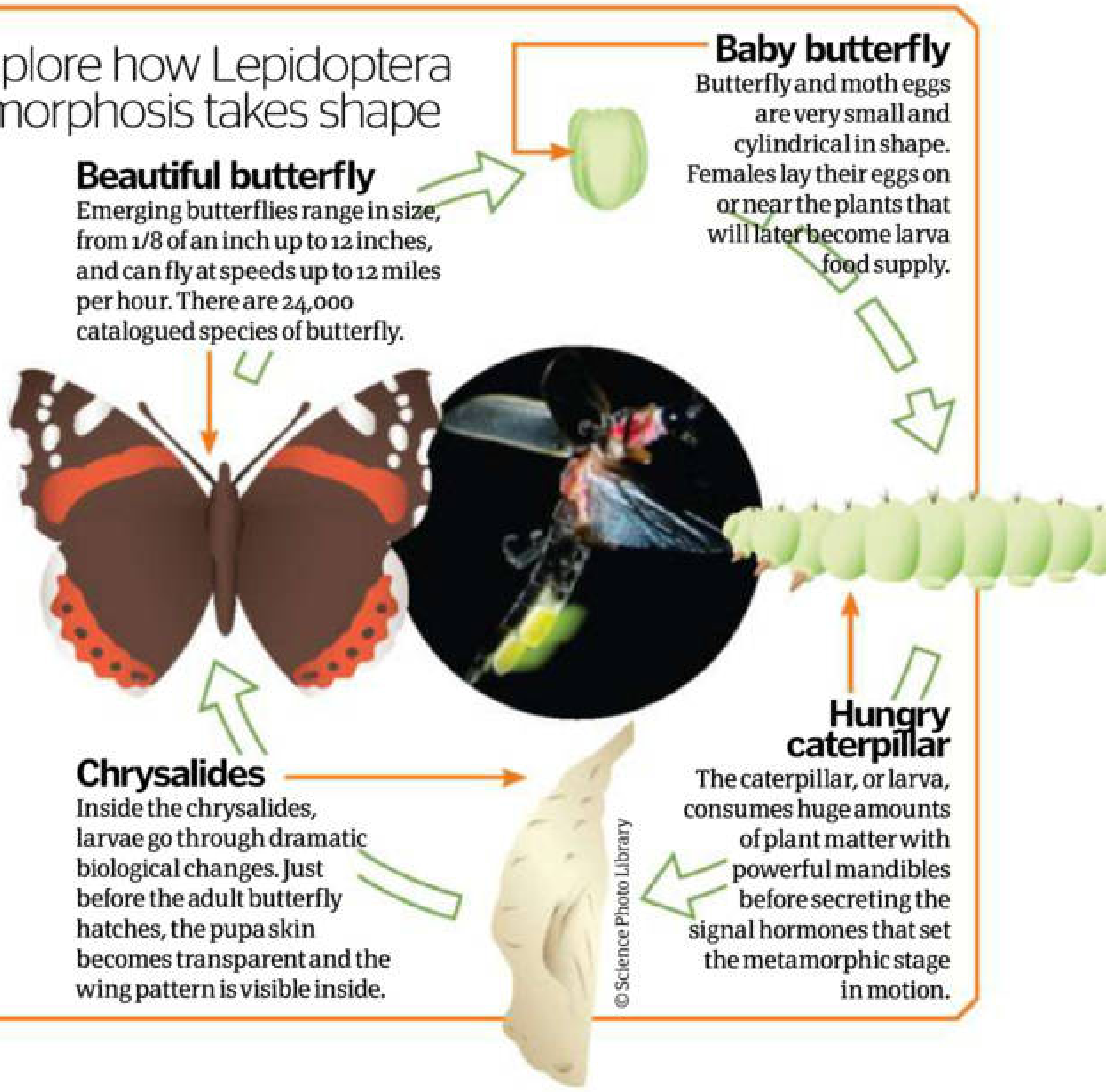
We explore how Lepidoptera metamorphosis takes shape

Member of the Lepidoptera family, butterflies are insects that achieve four life stages before turning into all manner of beautiful specimens, including Hesperiidae, Papilionidae and Nymphalidae. This amazing journey sees Lepidoptera begin life as a plain egg that hatches into a larva, or caterpillar, after a period of six days.

The caterpillar is an eating machine, consuming constantly for up to four weeks until pupation. Its anatomy makes it adept at consuming all types of plant matter. Using its three pairs of true legs and five pairs of 'prolegs' – sucker-like structures with clever little hooks on the end – it grips leaves and plant stems, munching away with powerful mandibles. The caterpillar has an astonishing 4,000 muscles to compliment these feeding habits and a long gut tract to quickly digest food.

This feasting fuels their growth, and a caterpillar will shed its husk several times, becoming stronger and larger each time. At this stage larvae begin to secrete signature hormones, which instigate the need to produce a protective silk cocoon – known as pupae or chrysalides – and initiate the metamorphic stage. They achieve this by using their modified set of salivary glands, called spinnerets. This cocoon may take the form of a small hollow in the earth lined with silk, or a roll of leaves, camouflaged to deter predators.

What really goes on inside cocoons is fascinating. Larva anatomy and organs rapidly dissolve and re-form into new tissue, limbs and wings of the adult butterfly. Some species take no more than two weeks – others whole winters – but all emerge as butterflies. Blood is pumped into the insect wings, making them expandable and ready to fly.



Baby butterfly Butterfly and moth eggs are very small and cylindrical in shape. Females lay their eggs on or near the plants that will later become larva food supply.

Beautiful butterfly Emerging butterflies range in size, from 1/8 of an inch up to 12 inches, and can fly at speeds up to 12 miles per hour. There are 24,000 catalogued species of butterfly.

Hungry caterpillar The caterpillar, or larva, consumes huge amounts of plant matter with powerful mandibles before secreting the signal hormones that set the metamorphic stage in motion.

Chrysalides Inside the chrysalides, larvae go through dramatic biological changes. Just before the adult butterfly hatches, the pupa skin becomes transparent and the wing pattern is visible inside.

© Science Photo Library

Ladybirds explained

The red-caped heroes of the insect world, ladybirds save the day for gardeners and farmers everywhere

Coccinellids, more commonly known as ladybirds, or ladybugs in North America, are members of the beetle family. There are more than four and a half thousand different species of ladybirds throughout the world living in warm and temperate regions. Though they vary widely in size and colouration, most of us know them as small red beetles with distinctive black spots, a friend of farmers and gardeners.

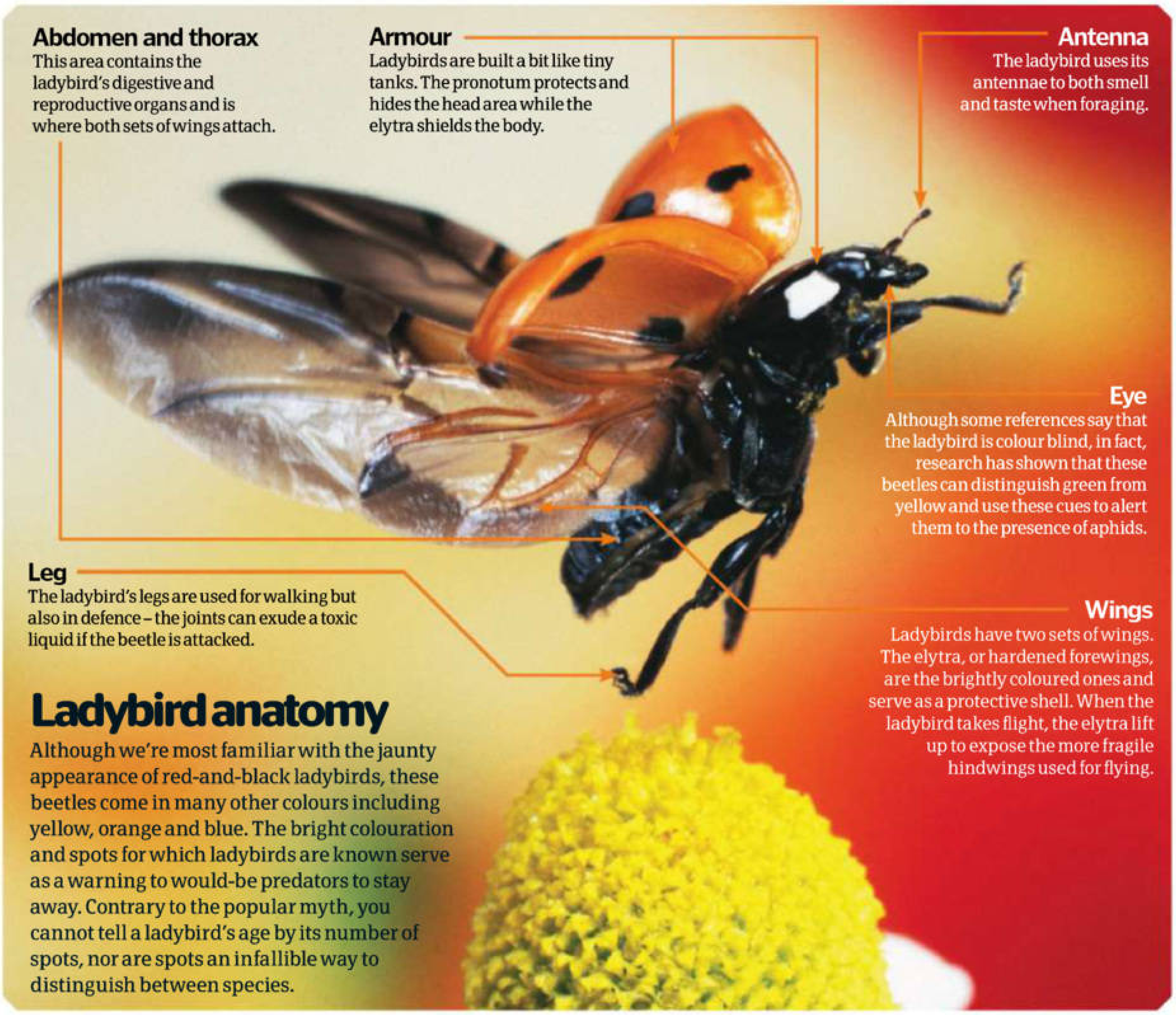
Like all beetles, ladybirds go through a huge metamorphosis on their way to adulthood. Ladybird eggs hatch into larvae, which oddly look a bit like tiny black-and-yellow alligators. These larvae grow and moult, going through several instars, or developmental phases, over a period of two to three weeks before finally pupating into adults.

Ladybirds feature aposematic or 'warning' colouration that gives potential predators advanced warning of their bad taste, and when threatened, they can exude a toxic and foul-smelling alkaloid liquid from their joints. In spite of their excellent defence system, ladybirds are not without enemies; parasitic wasps and flies occasionally attack them and some ladybirds fall victim to intrepid spiders and toads too.

Many native ladybird species are under threat from another ladybird species – the Asian or harlequin ladybird (harmonia axyridis). These invaders are generalist feeders and can out-compete resident ladybirds in their native range. They're also somewhat infamous for attempting to hibernate inside human dwellings where they may swarm, stain fabric and even cause allergic reactions.

Currently one-fifth of indigenous British ladybird species are on the decline. In addition to competition with the aforementioned Asian ladybird, climate change and altered land use patterns are likely contributors.

Not all the news is bleak however – a few native ladybirds are expanding their range, and one species – the 13-spot ladybird – previously thought to be extinct has recently been found in Cornwall and Devon.



Abdomen and thorax
This area contains the ladybird's digestive and reproductive organs and is where both sets of wings attach.

Armour
Ladybirds are built a bit like tiny tanks. The pronotum protects and hides the head area while the elytra shields the body.

Antenna
The ladybird uses its antennae to both smell and taste when foraging.

Eye
Although some references say that the ladybird is colour blind, in fact, research has shown that these beetles can distinguish green from yellow and use these cues to alert them to the presence of aphids.

Leg
The ladybird's legs are used for walking but also in defence – the joints can exude a toxic liquid if the beetle is attacked.

Wings
Ladybirds have two sets of wings. The elytra, or hardened forewings, are the brightly coloured ones and serve as a protective shell. When the ladybird takes flight, the elytra lift up to expose the more fragile hindwings used for flying.

Ladybird anatomy

Although we're most familiar with the jaunty appearance of red-and-black ladybirds, these beetles come in many other colours including yellow, orange and blue. The bright colouration and spots for which ladybirds are known serve as a warning to would-be predators to stay away. Contrary to the popular myth, you cannot tell a ladybird's age by its number of spots, nor are spots an infallible way to distinguish between species.

Aphids are popular ladybird fodder

What do ladybirds feed on?

Carnivores and cannibals, ladybirds are justifiably famous (and appreciated) for their habit of eating crop pests. Most ladybird species are carnivorous, consuming soft-bodied insects including aphids, mites, scale insects and white flies. Foraging ladybirds use visual and olfactory clues to home in on food-rich hunting and laying grounds. Newly hatched ladybird larvae have voracious appetites and, if there's insufficient prey available, they may even eat one another! Ladybird mothers also sometimes lay infertile eggs as an additional food source for their young during hard times.

A single ladybird may devour as many as 65 aphids per day. Females consume more than males and both genders eat more when the temperature is warmer, such as in a greenhouse. However, in spite of their reputation, not all ladybird species eat other insects and even the carnivorous species aren't carnivores all the time. Predatory ladybirds rely on pollen, nectar and other plant foods during periods of prey scarcity, and there is a small number of species who spend their lives dining on such delicacies as mildew and fungus.

Tardigrades

They may be small but are these minibeasts really the toughest creatures on the planet?

Tardigrades are tiny aquatic invertebrates, known as water bears for their slow gait. The largest species is 1.5 millimetres long, the smallest are under 0.1mm. Despite their squishy and vulnerable appearance, they are virtually indestructible. Lab experiments have shown that they can survive pressures of 6,000 atmospheres, temperatures as low as -272°C or as high as 151°C, and doses of radiation that would kill us a thousand times.

They achieve this by dehydrating their bodies with a sugar called trehalose, which acts as scaffolding protecting cell contents. Their water content drops to one per cent of normal in this state and metabolism slows by 99.99 per cent. Ice can't form in a body this dry and chemical reactions that might harm them occur too slowly to be a danger.

© Science Photo Library

Legs
All tardigrades have eight legs. Their name means 'slow walker'.

Mouthparts
Tardigrades have a circular mouth that pierces and sucks. Most feed on plants.

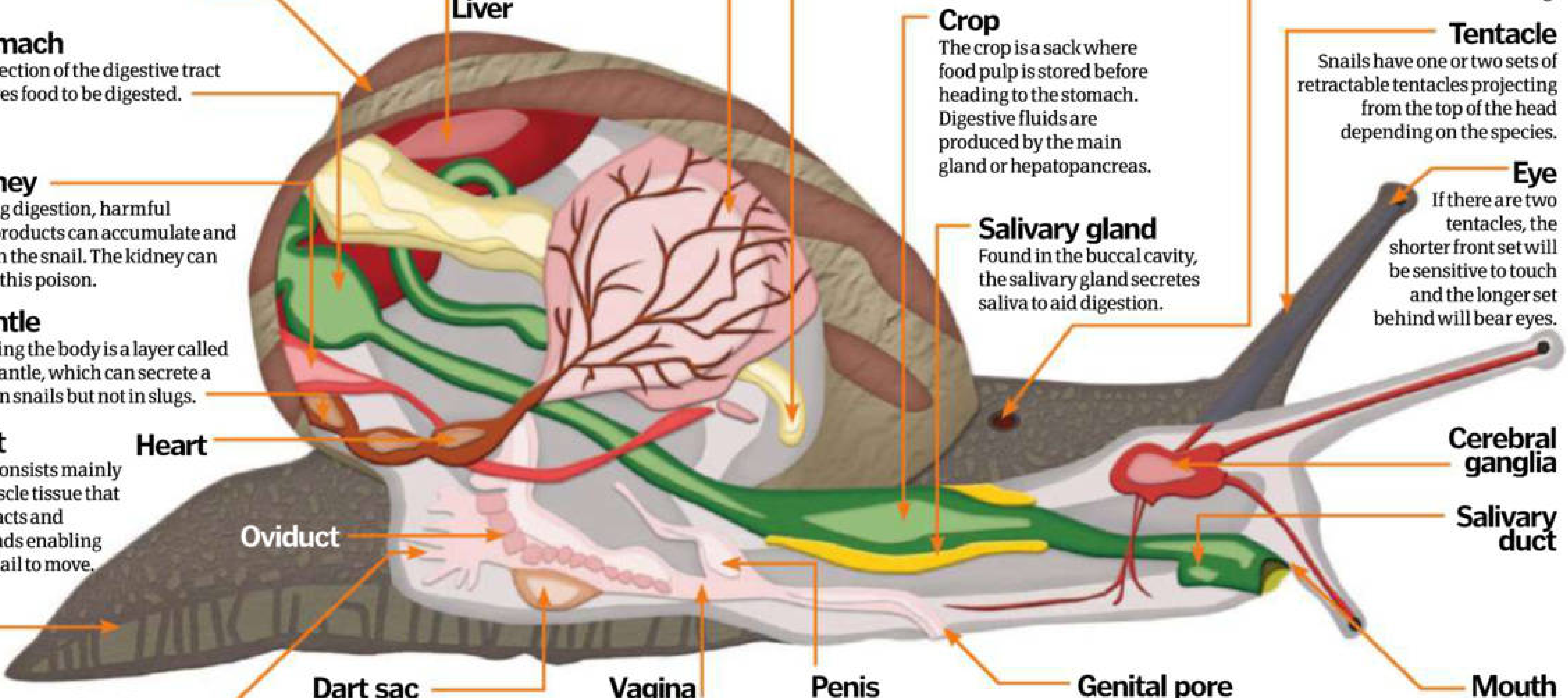
Moulting
Some species only defecate when they shed their skin, leaving the faeces behind inside the old skin.

Cell count
Tardigrades are eutelic, which means that individuals of the same species all have the same number of cells.

Senses
Some species have very simple, non-image-forming eyes, as well as sensory bristles.

Slugs and snails

The gardener's least favourite visitors, slugs and snails are incredible slime balls



Shell
Made of calcium carbonate, a snail's strong shell will remain so if the animal's diet contains enough calcium.

Stomach
This section of the digestive tract receives food to be digested.

Kidney
During digestion, harmful side-products can accumulate and poison the snail. The kidney can expel this poison.

Mantle
Covering the body is a layer called the mantle, which can secrete a shell in snails but not in slugs.

Foot
This consists mainly of muscle tissue that contracts and expands enabling the snail to move.

Heart

Lung
Not all snails have lungs but those that do have a single cavity containing a network of blood vessels that functions like a lung.

Liver

Anus
The intestine opens outside near the anus. As the snail crawls away it leaves behind a dark trail of faeces.

Crop
The crop is a sack where food pulp is stored before heading to the stomach. Digestive fluids are produced by the main gland or hepatopancreas.

Salivary gland
Found in the buccal cavity, the salivary gland secretes saliva to aid digestion.

Respiratory pore
Also called a pneumostome, this breathing pore is an opening through which air is breathed into the lung.

Tentacle
Snails have one or two sets of retractable tentacles projecting from the top of the head depending on the species.

Eye
If there are two tentacles, the shorter front set will be sensitive to touch and the longer set behind will bear eyes.

Cerebral ganglia

Salivary duct

Mucous gland
The mucous gland in the foot secretes thick, sticky slime to help the snail traverse tricky ground without injury.

Dart sac
Some land snails shoot a mucus-covered 'dart' into mates, delivering a substance that improves sperm survival.

Vagina
Female reproductive organ located on the ventral surface of the foot.

Penis
Male reproductive organ is located internally when not in use and is found on the ventral face of the foot.

Genital pore
Found at the side of the head, this opening allows copulation and exchange of sperm.

Mouth
The mouth features a jaw and a rough ribbon-like tongue called the radula for grazing on plants.

Although they look very different, slugs, snails, octopuses, oysters and cuttlefish are all molluscs – Latin for 'thin shelled' – and either have a calcium-carbonate external shell, a small shell under the surface, or no shell at all. Slugs are shell-less while adult snails have coiled shells big enough to withdraw into.

Slugs and snails belong to the large group of molluscs called gastropods and make their home in a variety of locations from back gardens to oceans and everywhere in-between. They are unique, being the only molluscs that can live on dry land, and breathe using either lungs, gills or both.

Gastropods are hermaphroditic, which means they have both male and female reproductive organs, and can mate with themselves if no partner is available. During an elaborate mating ritual slugs entwine and stimulate each other until sperm is exchanged via their disproportionately large genitals. Another peculiar trait is apophallation, whereby one slug chews off the other's penis after mating. The apophallated slug may now only reproduce using its female genitalia.

Termite mounds

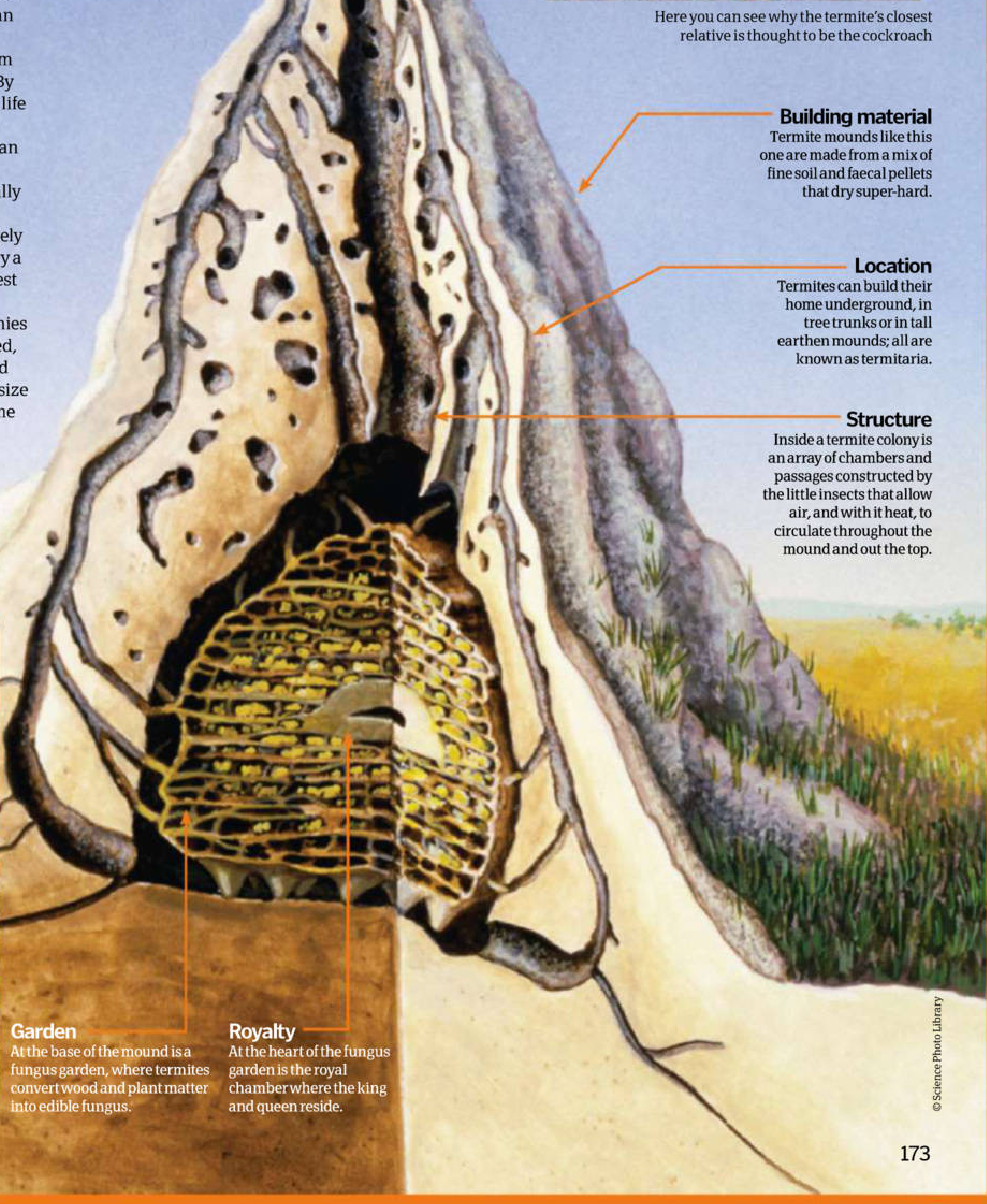
How does the wood-loving termite construct its home?

Termites are cellulose-eating insects that share many similarities with ants and bees, although, perhaps surprisingly, their closest relative is believed to be the cockroach. There are about 2,750 species of termite around the world, living in habitats as varied as tropical forests and the African savannah, through to the Pacific coast.

The eating habits of termites make them very important insects in an ecosystem. By consuming wooden structures and plant life they help convert dead trees into organic matter to trigger new life. However, this can cause problems, as they can eat through structural supports in buildings, eventually leading to their collapse.

Termites have evolved to eat wood largely because few other animals can; they carry a special bacteria that enables them to digest the tough cellulose fibres. This innate survival mechanism means termite colonies can be around for a very long time – indeed, some last up to 100 years. A termite mound (or termitarium) will reach its maximum size after four to five years, when it can be home to as many as 200,000 inhabitants.

Here you can see why the termite's closest relative is thought to be the cockroach



Building material
Termite mounds like this one are made from a mix of fine soil and faecal pellets that dry super-hard.

Location
Termites can build their home underground, in tree trunks or in tall earthen mounds; all are known as termitaria.

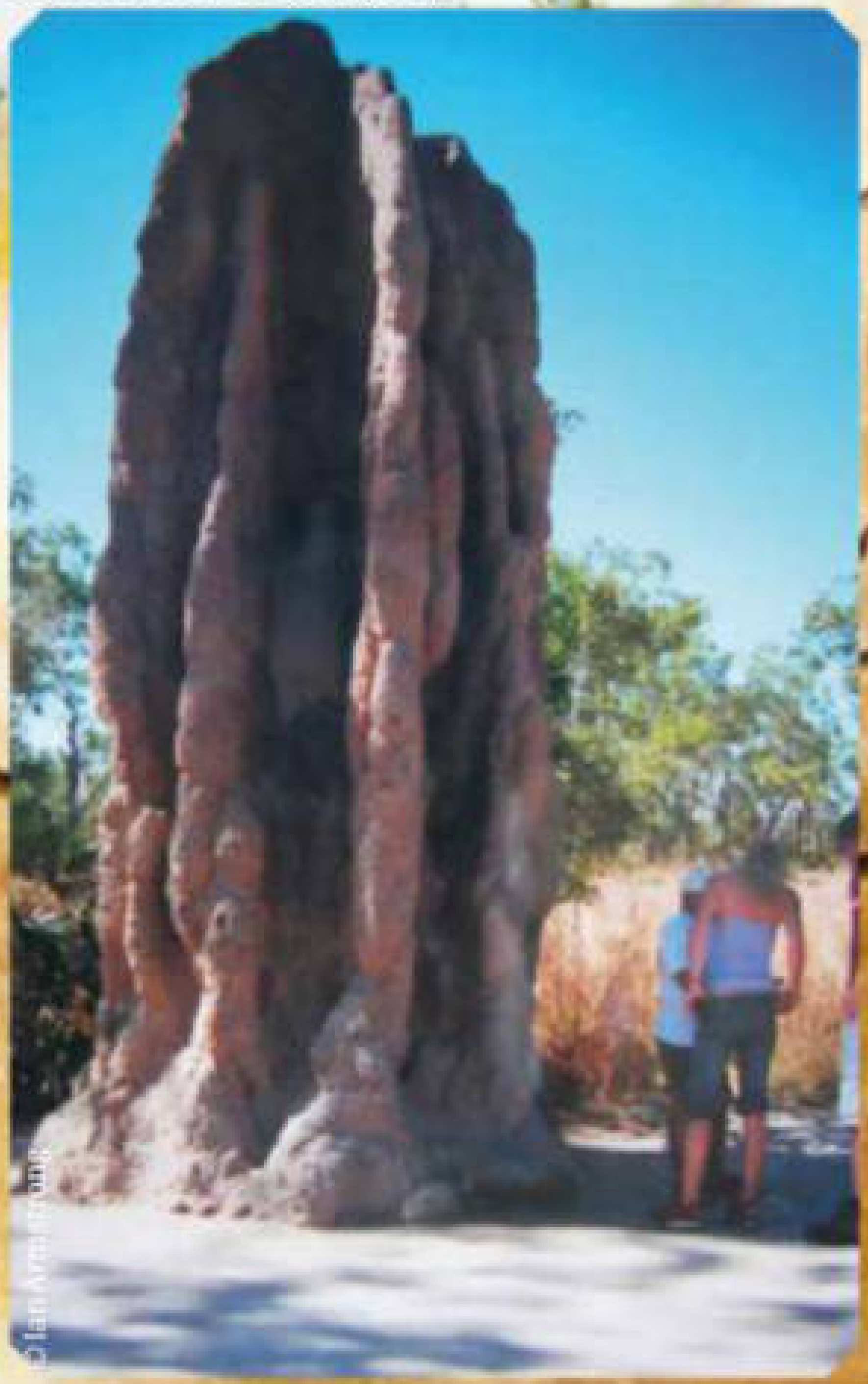
Structure
Inside a termite colony is an array of chambers and passages constructed by the little insects that allow air, and with it heat, to circulate throughout the mound and out the top.

Garden
At the base of the mound is a fungus garden, where termites convert wood and plant matter into edible fungus.

Royalty
At the heart of the fungus garden is the royal chamber where the king and queen reside.

© Science Photo Library

Some termite mounds can reach as tall as 9m (30ft)



© Ian Armstrong

Scorpions

The mascot of choice for international supervillains, these sinister stingers are also fearsome hunters

Arching its tail over its back, the scorpion delivers its deadly venom

© Guy Haimovitch

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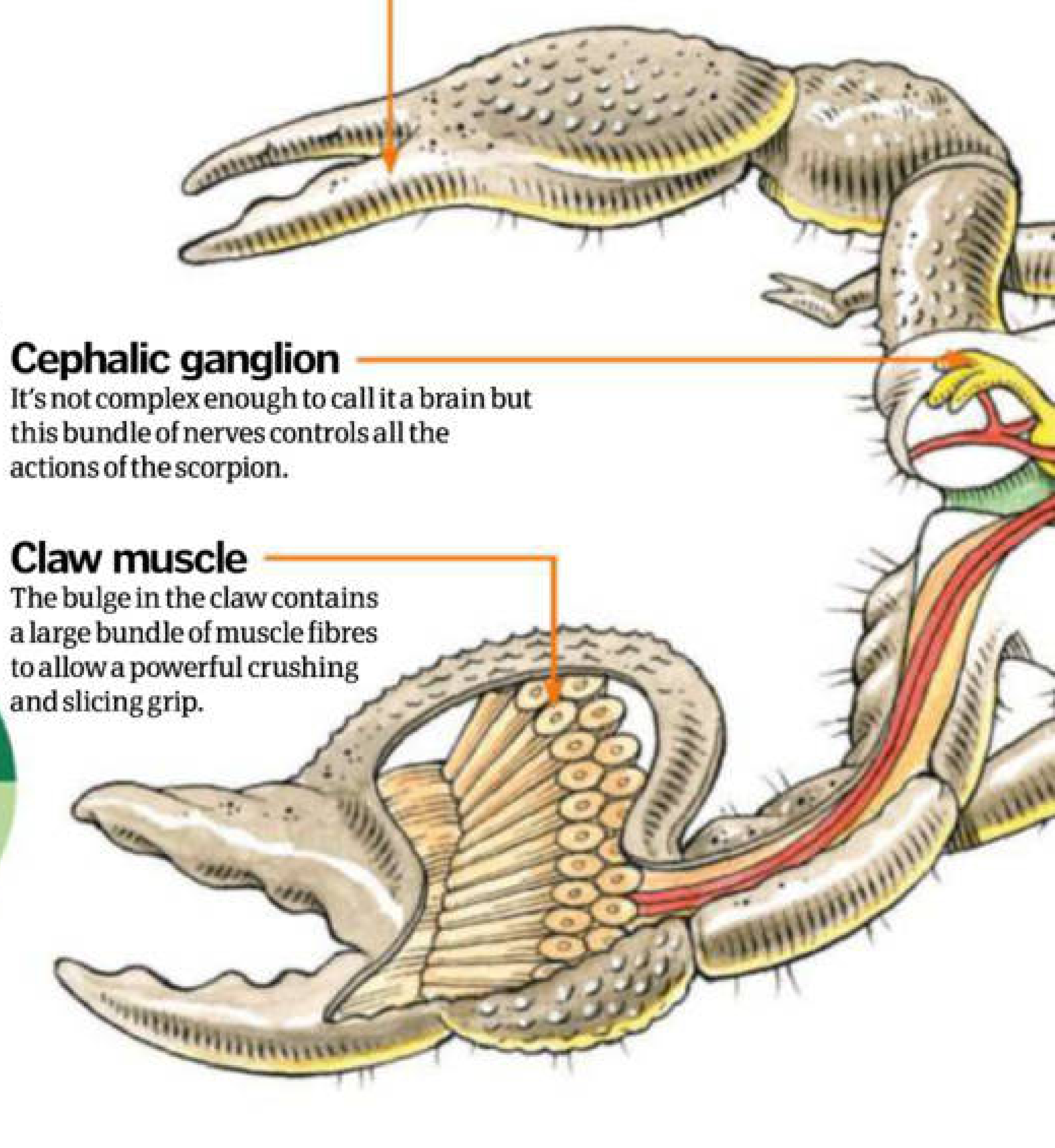
Scorpions are arachnids, like spiders. However, whereas spiders are mainly ambush predators, scorpions go looking for their lunch. Scorpions have between two and ten eyes, depending on the species, but their eyesight is poor and most scorpions are nocturnal anyway.

Instead they rely on vibration-sensitive legs, and hairs on their body that can detect the lightest touch or air current. A desert scorpion can feel the vibrations caused by the footsteps of a walking insect from a metre away. By comparing the time it takes the surface vibration to reach each leg, the scorpion can triangulate the position of its target. When it is close enough, the scorpion makes a brief dash to snatch its prey in powerful pincers. These claws, or chelae, are not true legs but are instead modified feelers. With the victim firmly grasped in its clutches, the scorpion arches its tail over its back to inject a powerful venom that incapacitates its meal within seconds.

Scorpions can't eat solid food directly, so they feed in a two-stage process. First they tear off small pieces with claw-like mouthparts, called chelicerae. These morsels are placed in a small cavity under the mouth and digestive juices are squirted up from the gut like ketchup. After the enzymes have liquidised the food, it can be slurped down into the stomach. Scorpions can eat several times their body weight at a single sitting and store this away for leaner times. They have very slow metabolisms and many species live for over ten years. If necessary they can manage with just one or two meals a year.



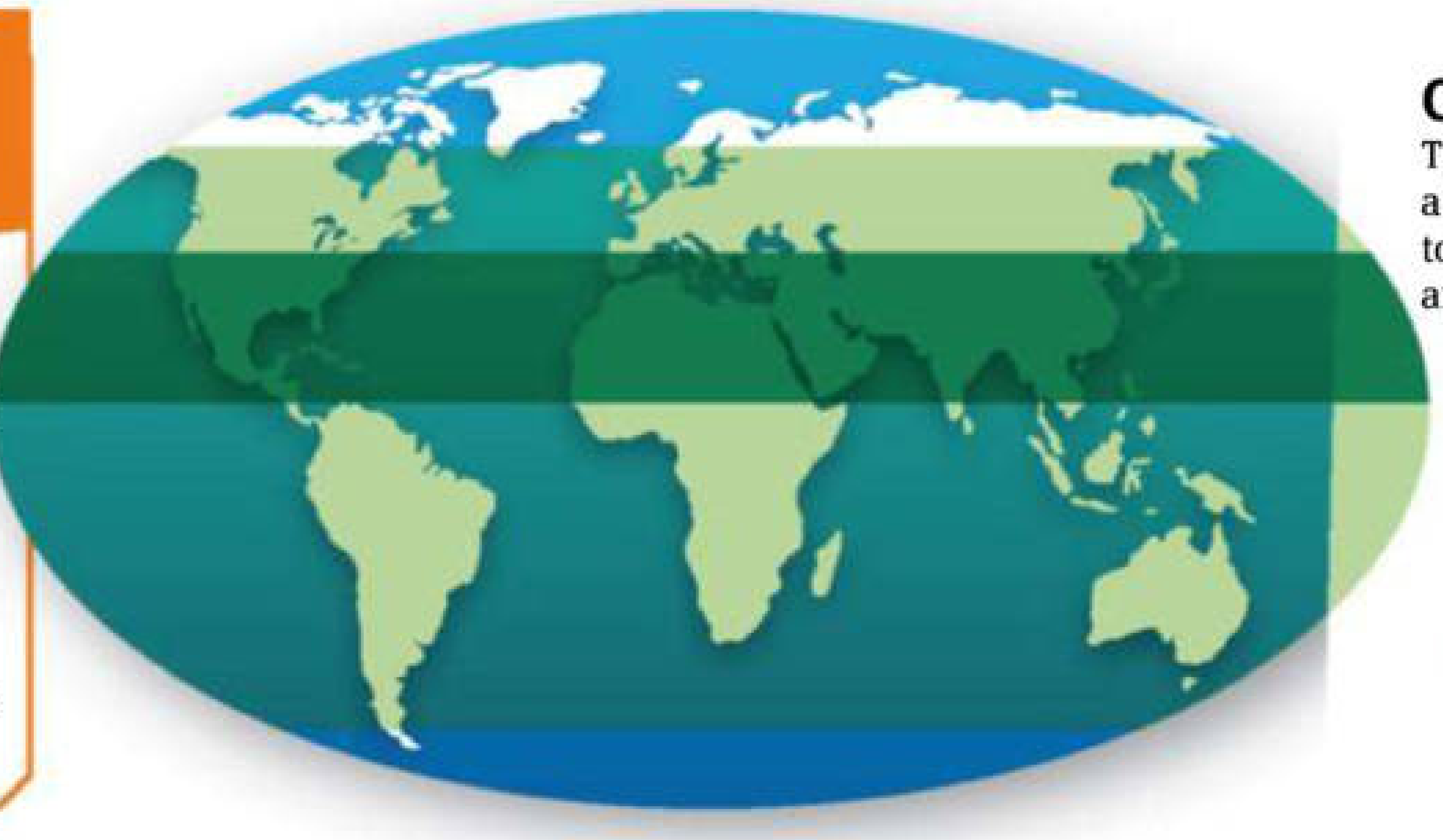
Claw
The outer half of the claw is fixed and called the tarsus. The inner, movable, section is called the manus. Collectively, the pincer is called a chela.

Cephalic ganglion
It's not complex enough to call it a brain but this bundle of nerves controls all the actions of the scorpion.

Claw muscle
The bulge in the claw contains a large bundle of muscle fibres to allow a powerful crushing and slicing grip.

ON THE MAP

Finding scorpions
Scorpions have a very wide distribution and are found on every continent apart from Antarctica. The dark zone on the map represents the greatest scorpion diversity but they can be found as far north as Kent in the UK and as far south as New Zealand.



Party animals

How do scorpions glow in ultraviolet?

All scorpions are fluorescent. This means that they glow when shone with ultraviolet light. This rather funky property is an accidental side effect of the way their armour plating is constructed. When scorpions first shed their skin, the new skin underneath is soft and vulnerable. To harden it up, the protein chains are cross-linked using other compounds. This process is called sclerotisation and is similar to the way that cowhide is turned into leather. In scorpions, the cross-linking compound is beta-carboline, which is strongly fluorescent. As a result scorpions glow more and more brightly under UV light with each successive moult.

A deadly and bright creature

© Fritz Geller-Grimm

Only 25 species have venom capable of killing a human

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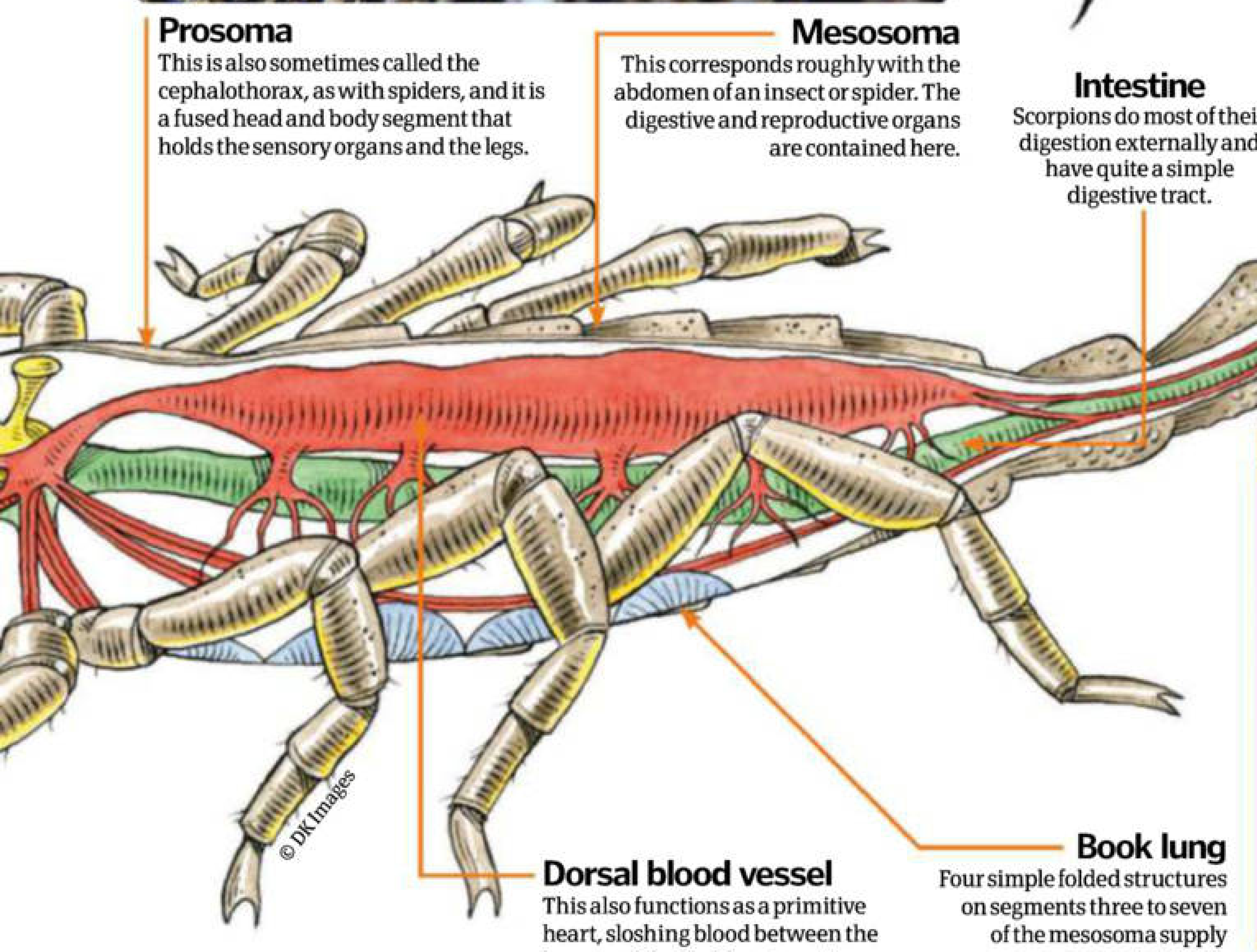

Telson
The sting or telson is a hollow needle that injects the venom. The two poison glands can adjust the dose according to the size of prey.

Metasoma
The tail is made from the last six segments of the body. The anus opens at the end, just before the sting.

Prosoma
This is also sometimes called the cephalothorax, as with spiders, and it is a fused head and body segment that holds the sensory organs and the legs.

Mesosoma
This corresponds roughly with the abdomen of an insect or spider. The digestive and reproductive organs are contained here.

Intestine
Scorpions do most of their digestion externally and have quite a simple digestive tract.

Dorsal blood vessel
This also functions as a primitive heart, sloshing blood between the lungs and the bodily extremities.

Book lung
Four simple folded structures on segments three to seven of the mesosoma supply oxygen to the blood.

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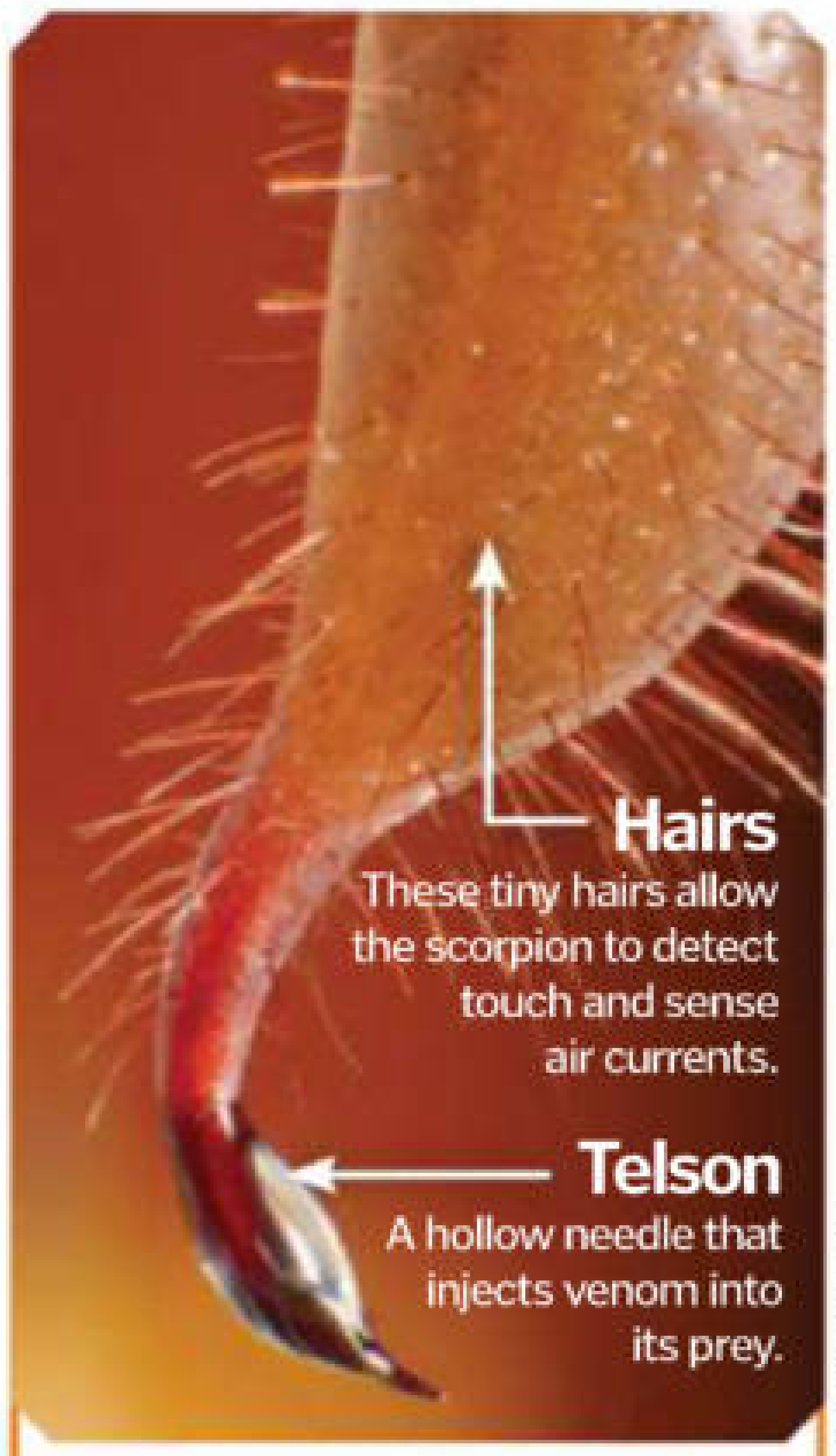

Hairs
These tiny hairs allow the scorpion to detect touch and sense air currents.

Telson
A hollow needle that injects venom into its prey.

ThinkStock

Sting in the tail

Scorpions are fast, strong and armoured, but they aren't invulnerable and relying on sheer brute strength when you are tackling prey almost as large as you is always risky. To tilt the scales in their favour, all scorpions are equipped with fast-acting venom which is delivered through a curved, hollow barb located on the end of their tail.

Scorpion venom is a cocktail of hundreds of different neurotoxins and enzyme inhibitors. This broad spectrum of chemicals allows the scorpion to target several different biological systems at once; some compounds paralyse muscles, others cause cell damage. Scorpions have also evolved different toxins to target different animals. For example, insect and mammal nervous systems work in quite different ways, and by combining all these chemicals into a single venom, scorpions have created a silver bullet that can take down almost anything. Despite this, our sheer size is our biggest defence and only 25 species of scorpion are deadly to humans.

The Statistics...

© Danny Steaven

Scorpions

Type: Arachnid
Diet: Carnivore
Average life span in the wild: 4-25 years
Weight: 4-60g
Size: 12mm-20cm

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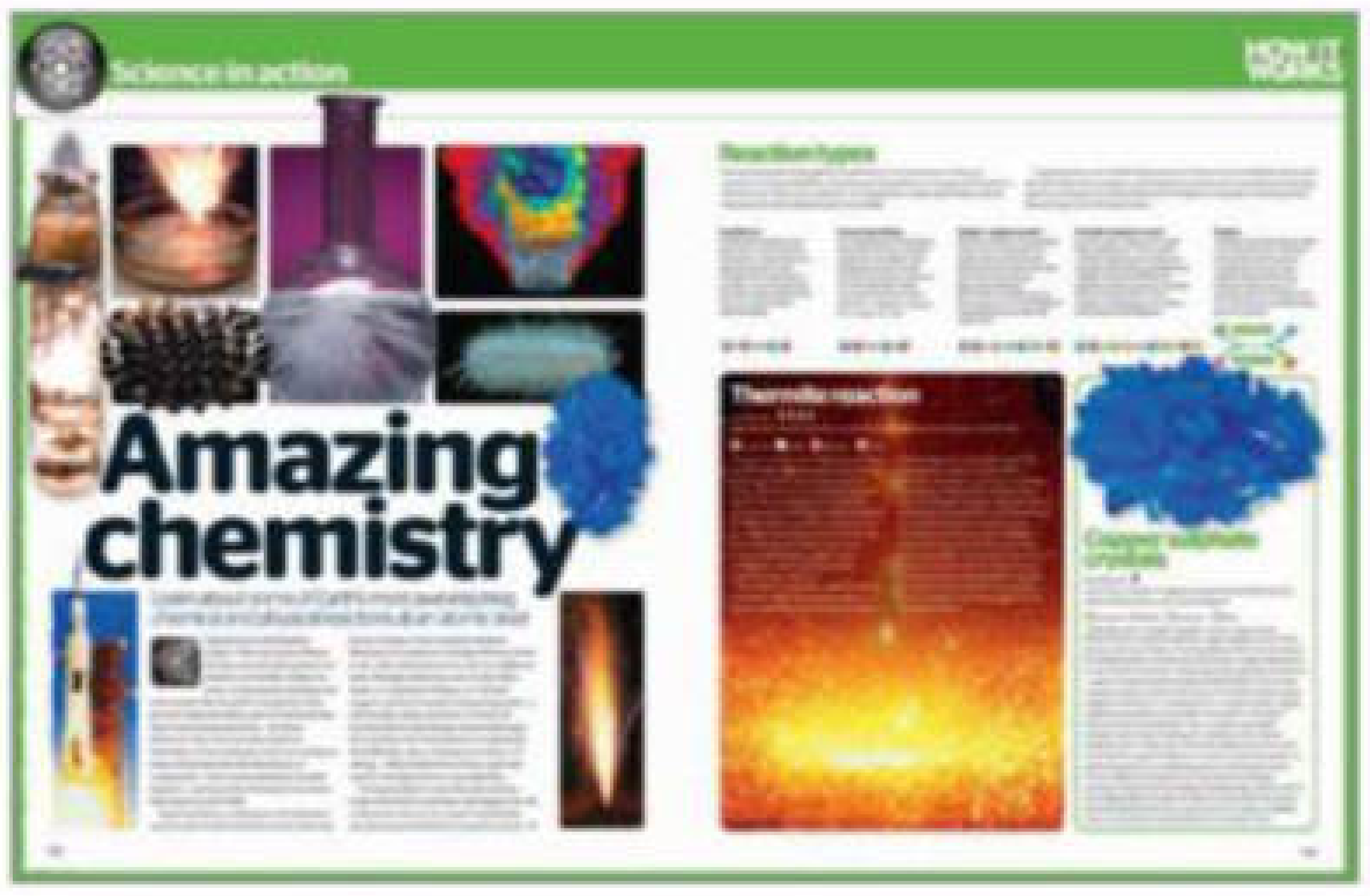
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